Searching for Dark Matter with LZ

Hugh Lippincott, Fermilab

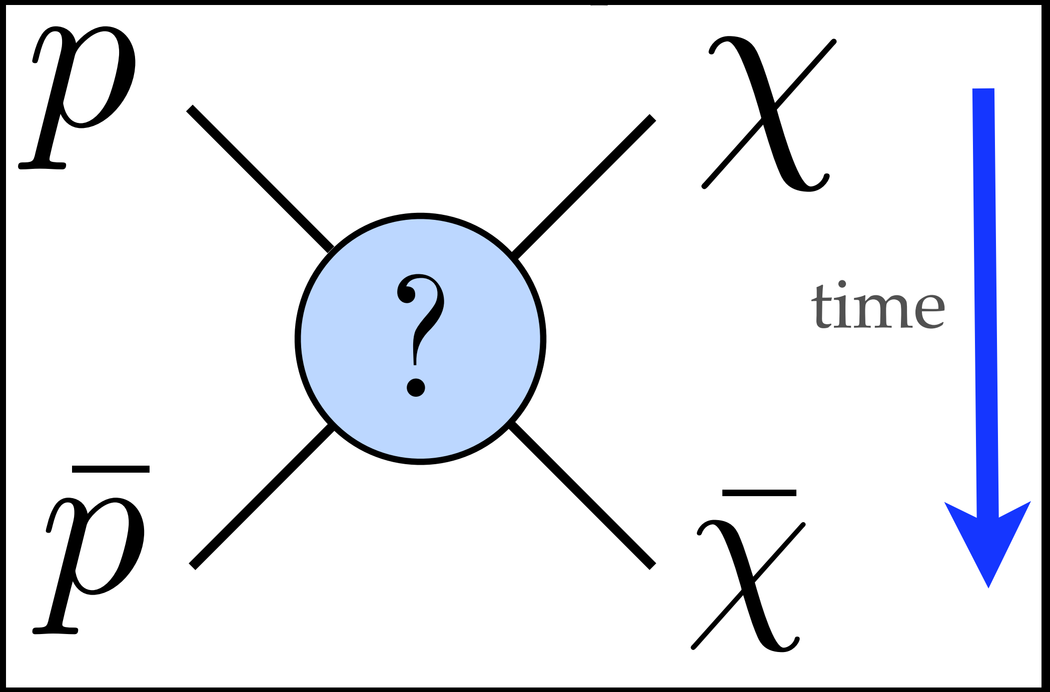
LPC Physics Forum
September 14, 2017

Skipping 8 slides

- We think dark matter exists for lots of reasons
- Nothing in the standard model works
- There are lots of theories about what it might be, including WIMPs
  - SUSY is a great paradigm for that, but not the only one
- Indirect, direct, collider searches

Direct Detection

- Calculate rate based on assumptions about the dark matter distribution and interaction



- Historically two interactions are considered (by DM experimentalists)
  - Spin independent (SI) - couples to all nucleons
    - Enhancement for large nuclei
  - Spin dependent (SD) - couples to the spin of the nucleus (unpaired spin of one nucleon)

Rate calculation

- The differential cross section (for spin-independent interactions) in events/kg/keV mass per unit recoil energy is

$$\frac{dR}{dQ} = \frac{\rho_0}{m_\chi} \times \frac{\sigma_0 A^2}{2\mu_p^2} \times F^2(Q) \times \int_{v_m} \frac{f(v)}{v} dv \tag{3}$$

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- The velocity distribution of dark matter in the galaxy - of order 30% uncertainty (not-statistical), and $v_m = \sqrt{Q m_N / 2 m_r^2}$ (here $m_r = m_N m_\chi/(m_N + m_\chi)$ is the reduced mass of the nucleus)

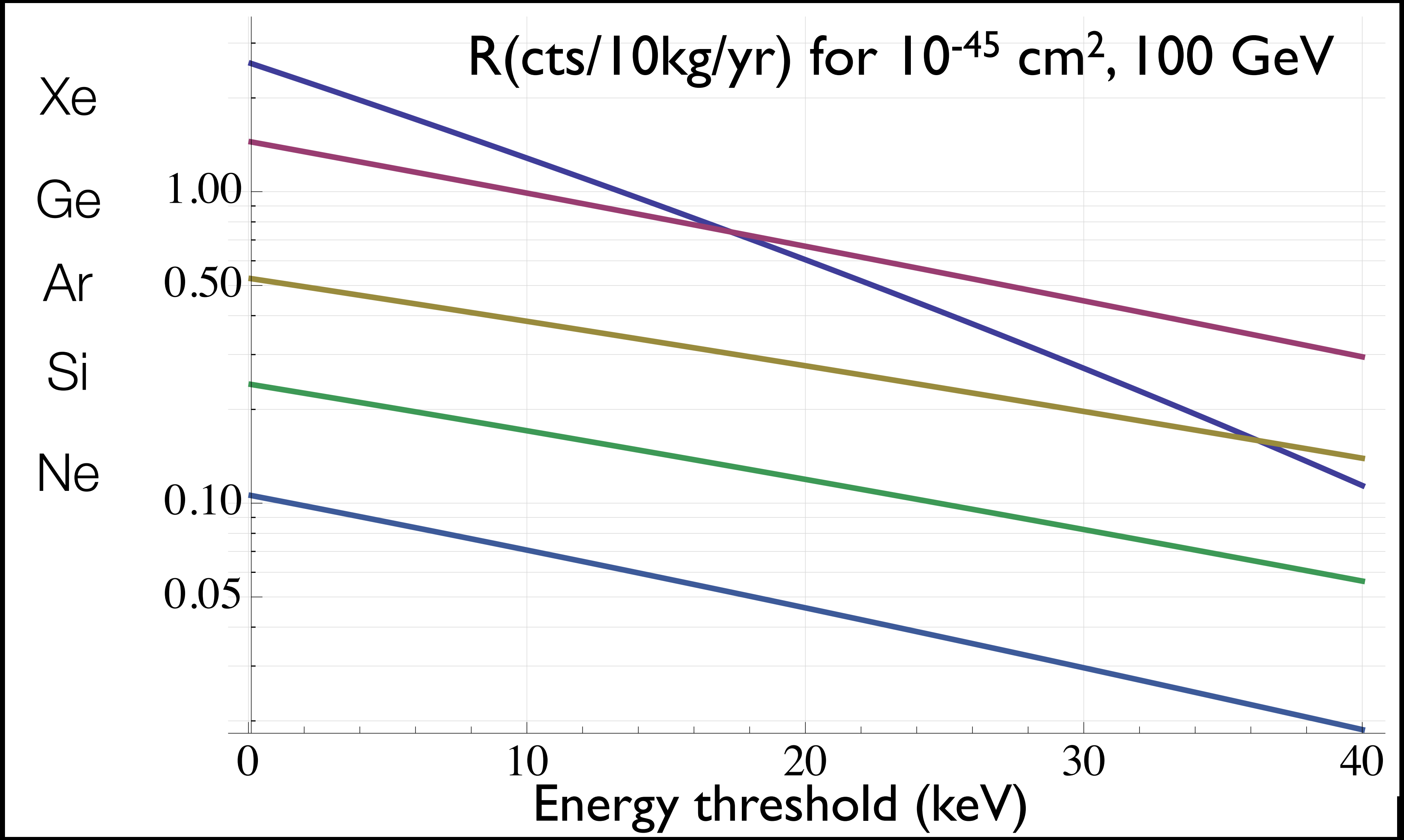
The energy scale

- Energy of recoils is tens of keV
- Entirely driven by kinematics, elastic scattering of things with approximately similar masses (100 GeV) and v ~ 0.001c

$$\frac{1}{2} m_N v_N^2 = \frac{1}{2} \times 100\,\mathrm{GeV} \times 10^{-6} = 50\,\mathrm{keV}$$

How do we find it?

- Very low rate process (~events/year)



- Rate depends crucially on WIMP mass and threshold

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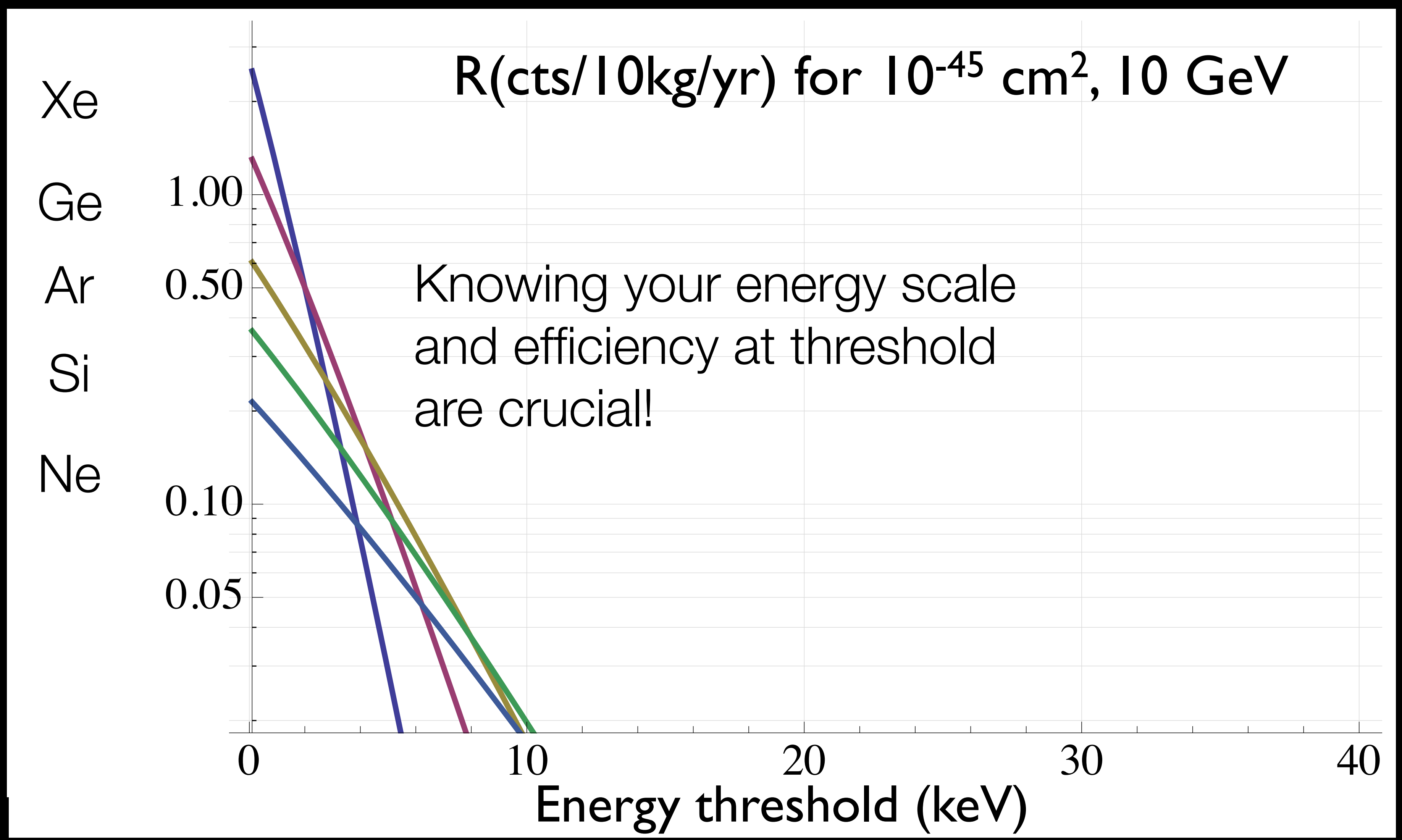

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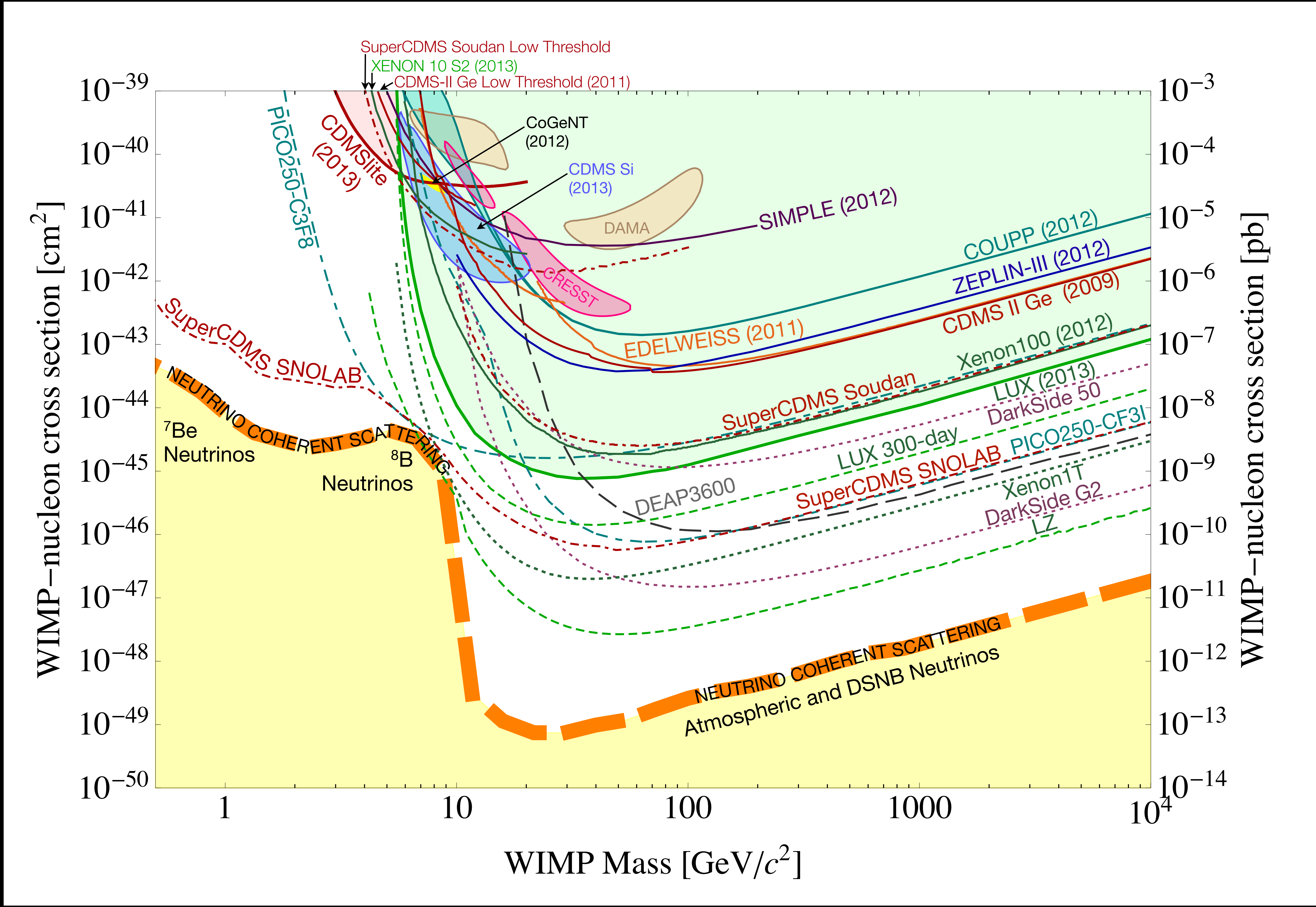
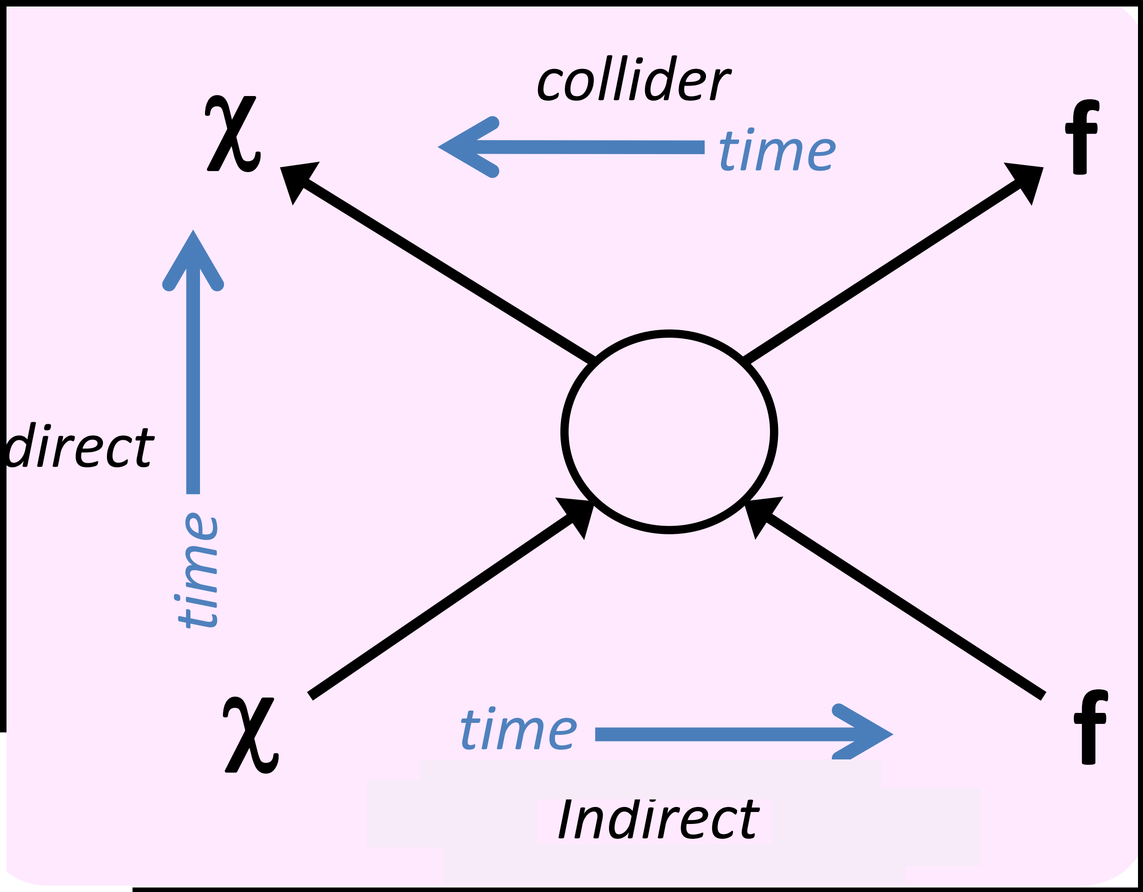
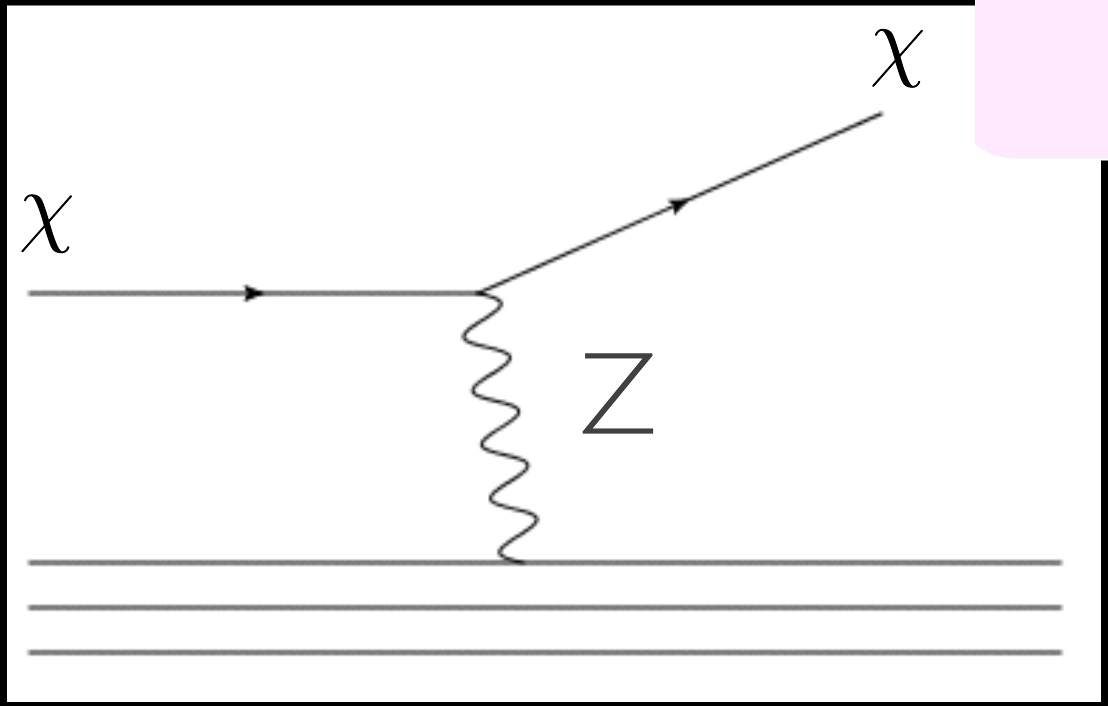


- Limited at low mass by detector threshold
- Limited at high mass by density
- Eventually limited by neutrinos

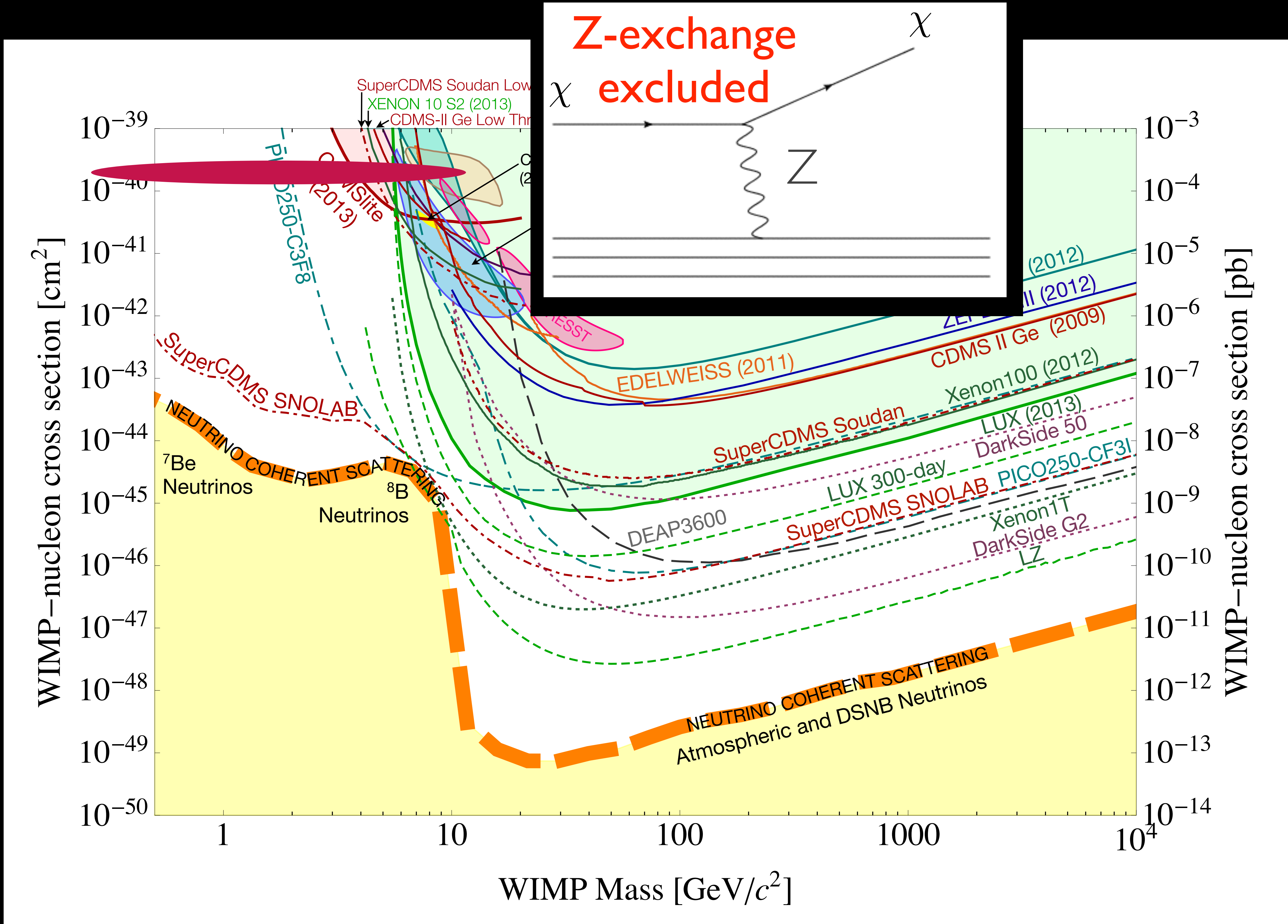
$$\langle \sigma v \rangle_{ann} \approx 3 \times 10^{-26} \mathrm{cm}^3 \mathrm{sec}^{-1}$$
$$\approx \frac{\alpha^2}{(200\mathrm{GeV})^2}$$

Coupling e.g. to light quarks



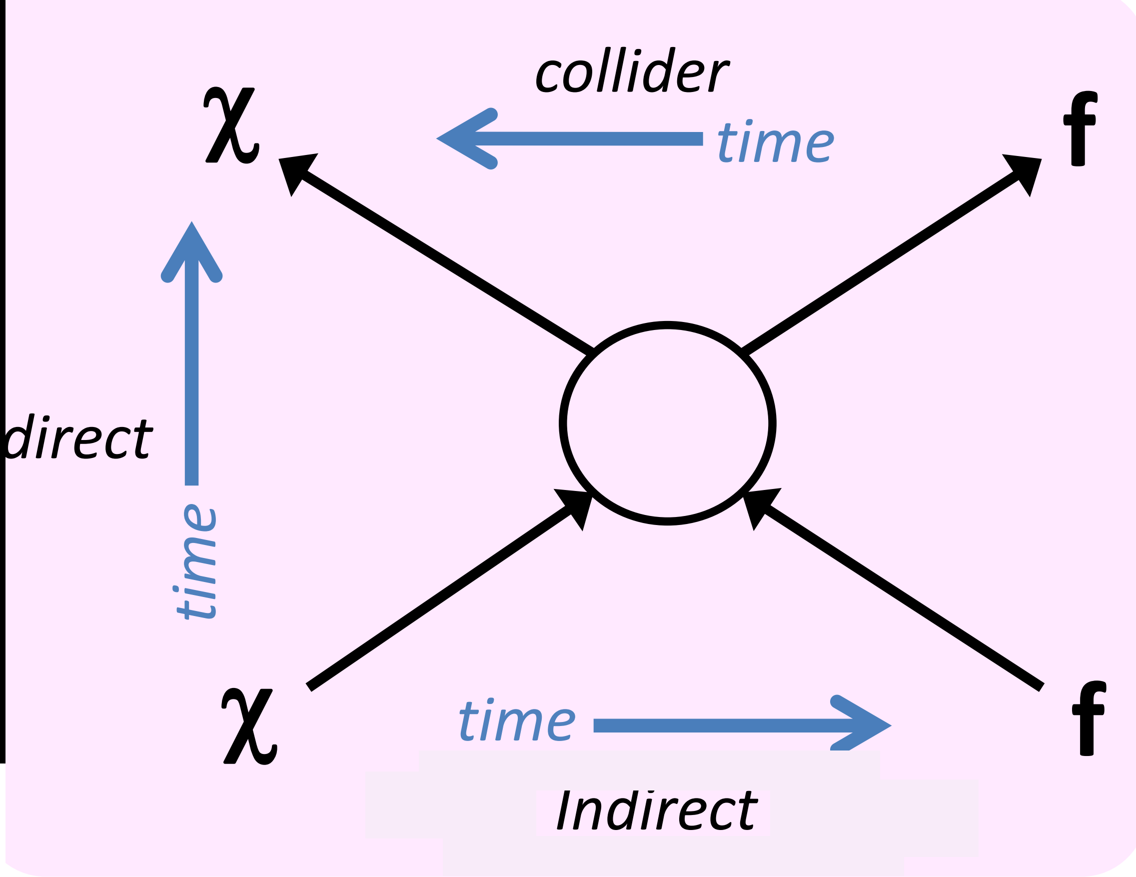


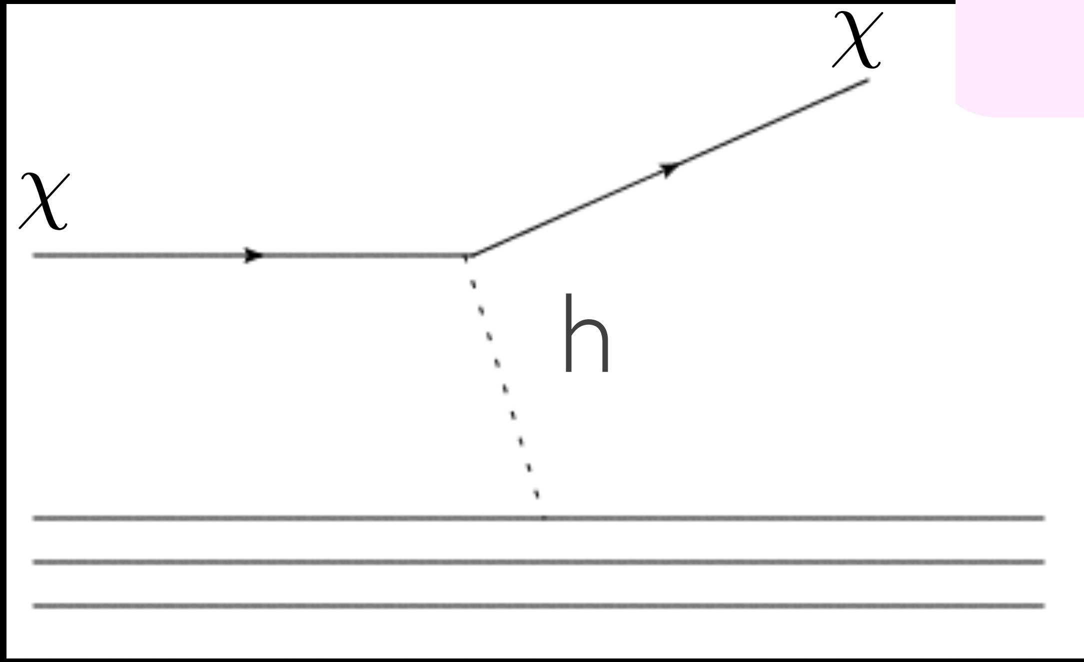
$$\sigma_0 \approx \frac{G_f^2 \mu^2}{2\pi} \sim 10^{-39} \mathrm{cm}^2$$


Z-exchange
excluded
χ
χ
Z
SuperCDMS Soudan Low
XENON 10 S2 (2013)
CDMS-II Ge Low Thr
SuperCDMS SNOLAB
NEUTRINO COHERENT SCATTERING
7Be Neutrinos
8B Neutrinos
EDELWEISS (2011)
CDMS II Ge (2009)
Xenon100 (2012)
SuperCDMS Soudan
LUX (2013)
DarkSide 50
LUX 300-day
PICO250-CF3I
SuperCDMS SNOLAB
DEAP3600
Xenon1T
DarkSide G2
LZ
NEUTRINO COHERENT SCATTERING
Atmospheric and DSNB Neutrinos
WIMP–nucleon cross section [cm2]
WIMP–nucleon cross section [pb]
WIMP Mass [GeV/c2]

$$< \sigma v >_{ann} \approx 3 \times 10^{-26} \mathrm{cm}^3 \mathrm{sec}^{-1}$$
$$\approx \frac{\alpha^2}{(200\mathrm{GeV})^2}$$

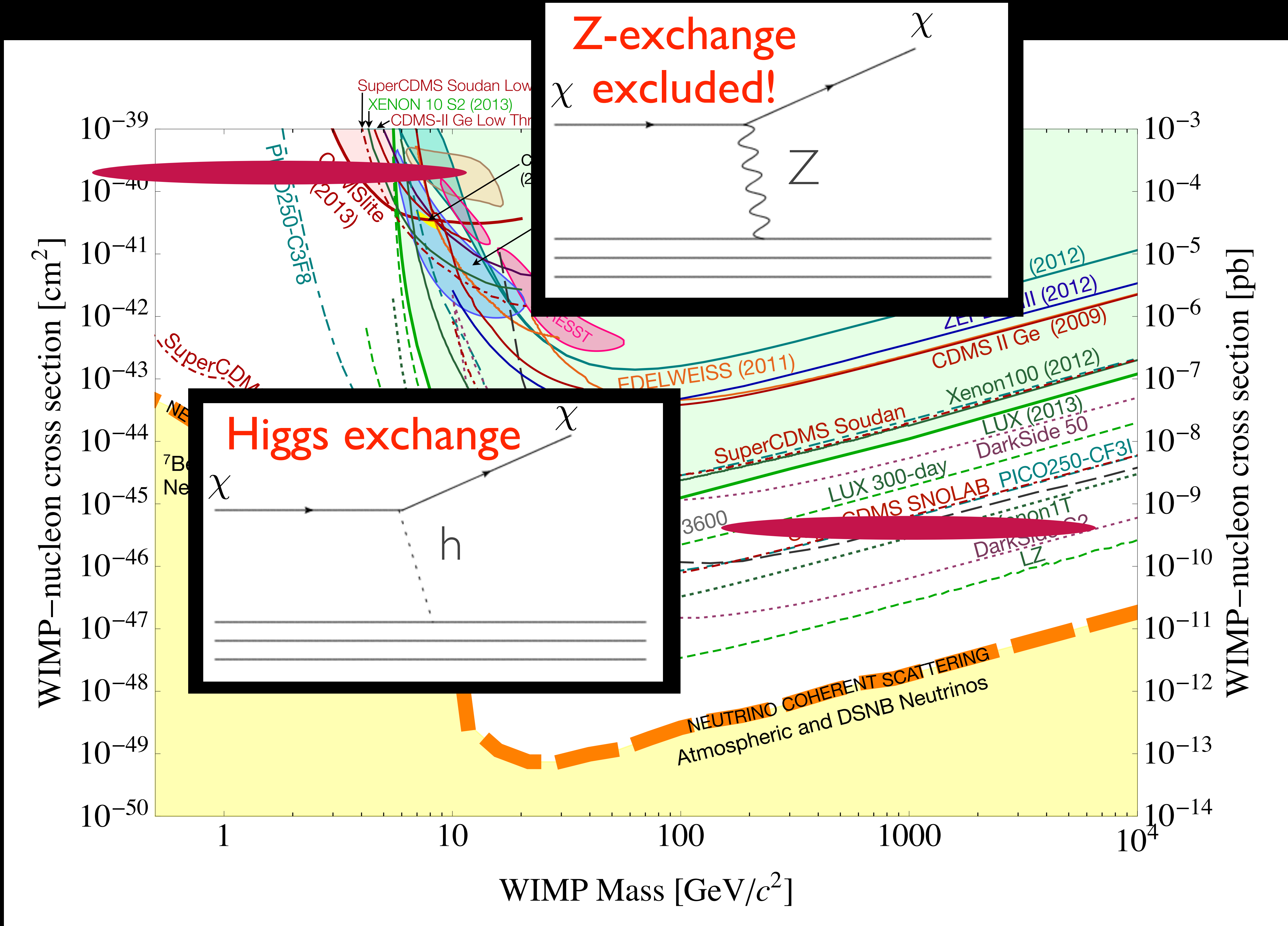
Coupling proportional to mass (e.g. via higgs)





$$g \sim 1 \Rightarrow y_p \sim \frac{1}{\mathrm{few}} \frac{m_p}{v}$$

$$\sigma_0 \sim 10^{-39} \mathrm{cm}^2 \times 10^{-6}$$
$$\sim 10^{-45} \mathrm{cm}^2$$

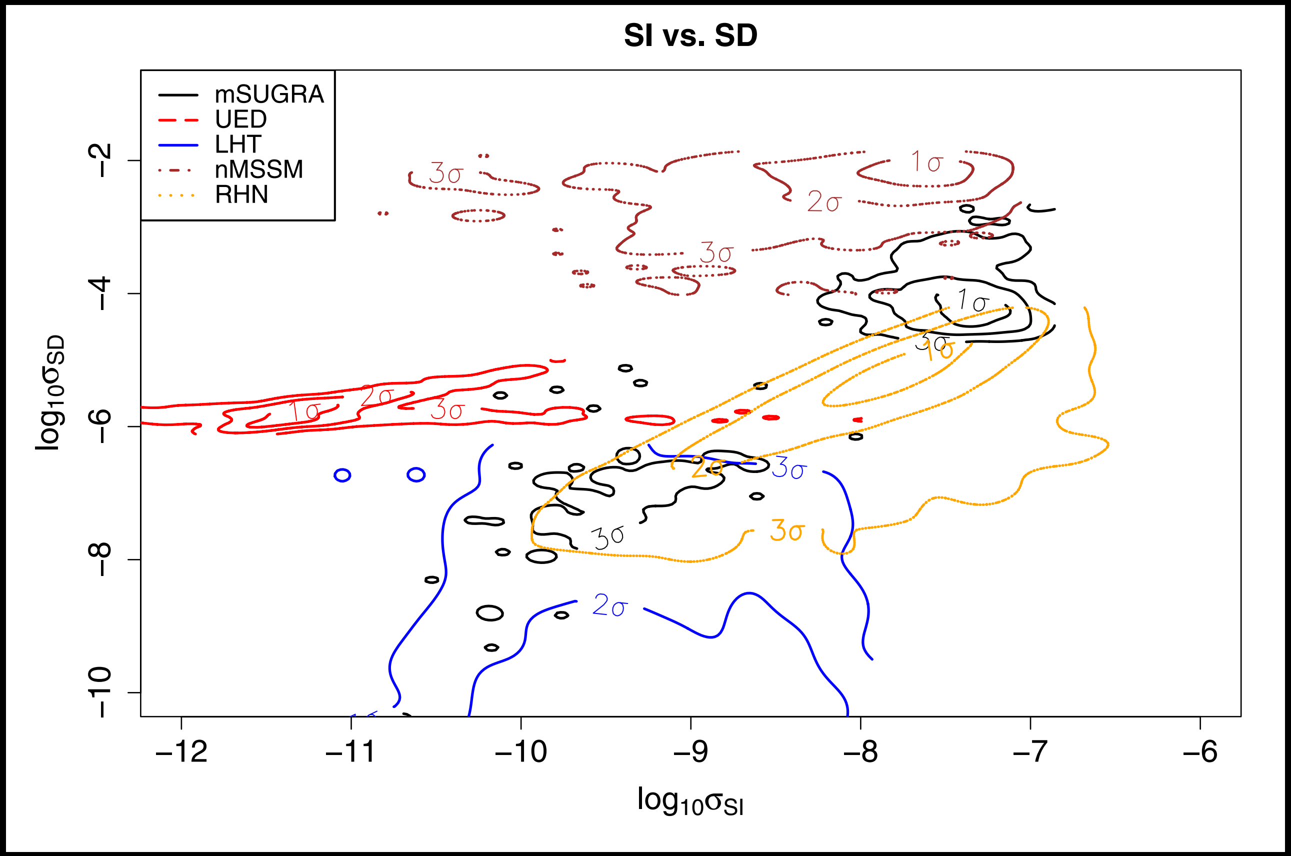


"This era will answer the question: does the dark matter couple at O(0.1) to the Higgs boson"

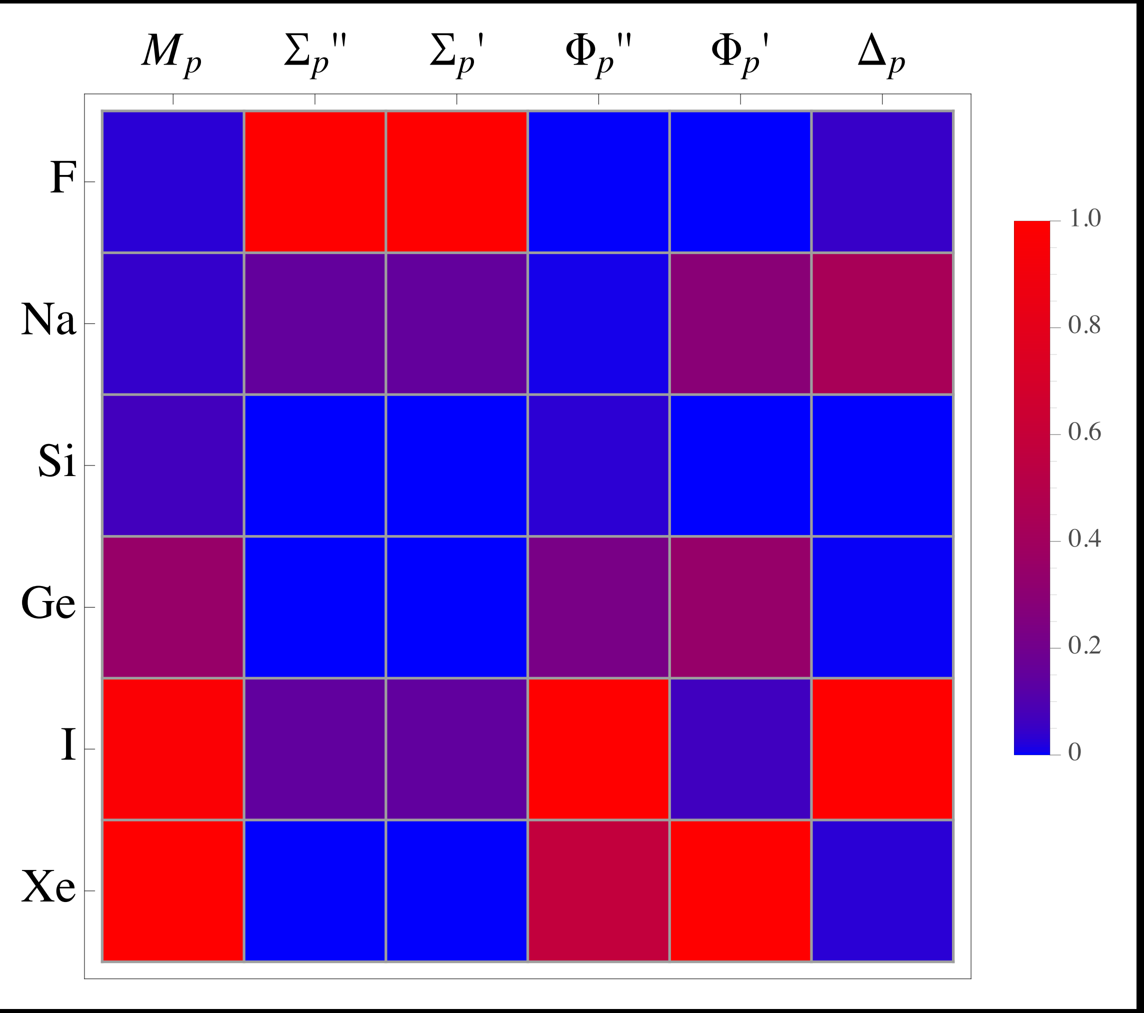
N. Weiner, CIPANP 2015

SI vs. SD (vs. nuclear physics)

- Spin-independent historically dominates the news because of the rate enhancement (x16000 for an atom like xenon)
- True interaction is still unknown



SD vs. SI cross section predictions for different models (Barger, PRD, 78 056007)



Sensitivity of different p-coupling operators to various nuclear targets
(from L. Fitzpatrick at INT Workshop, 2014)

So we look for WIMPs

- A billion WIMPs pass through us per second - we might expect a handful of counts in a detector per year

So we look for WIMPs

- A billion WIMPs pass through us per second - we might expect a handful of counts in a detector per year
- The problem is that background radioactivity is everywhere!

100 events/second/kg =
3,000,000,000,000 events/year
in a ton-scale experiment

Backgrounds!

Background sources

- Cosmic rays are constantly streaming through
    - All experiments have to go underground to get away from cosmic rays


SNOLAB
MINING FOR KNOWLEDGE
CREUSER POUR TROUVER... L'EXCELLENCE

Background sources

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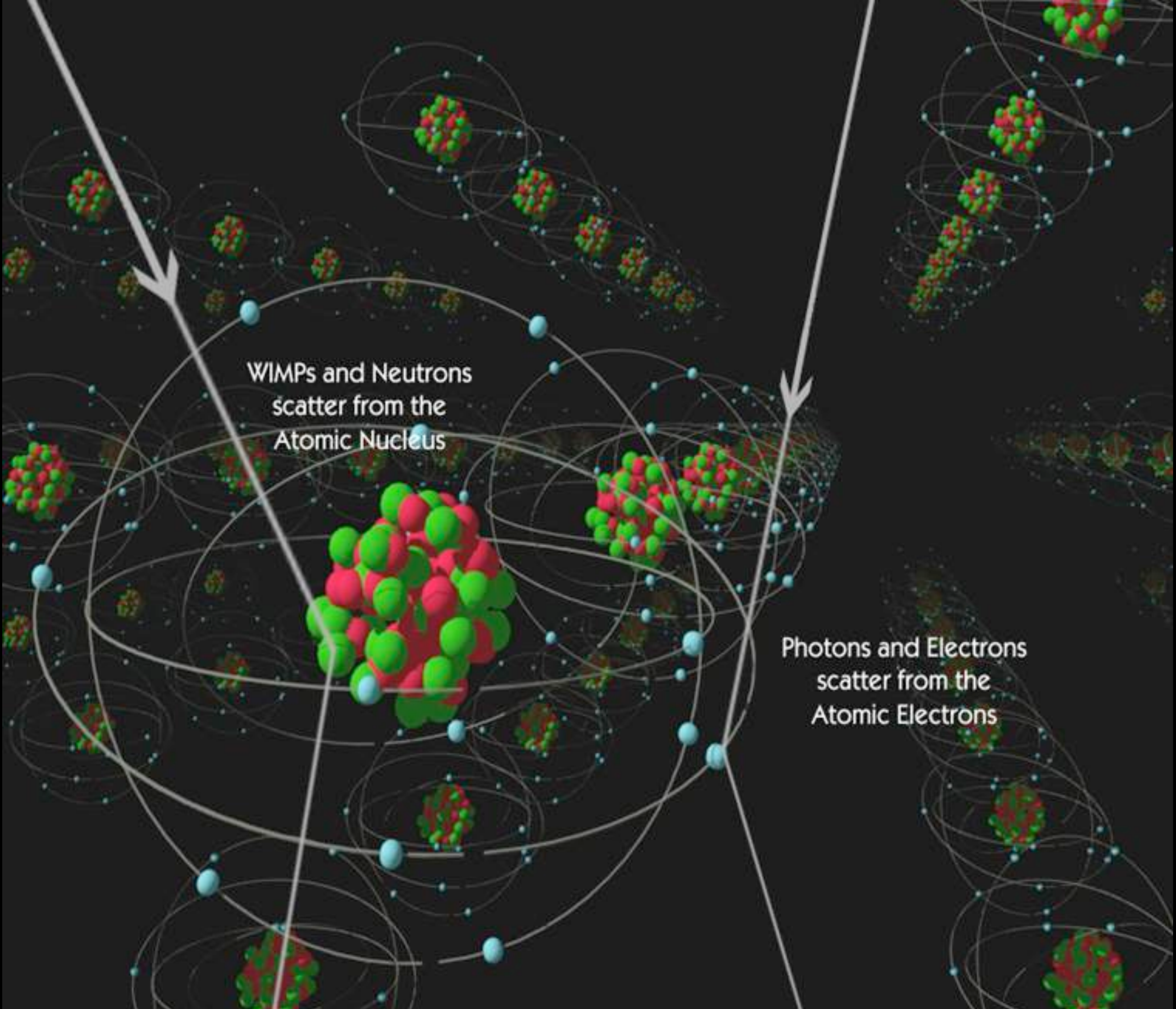
- Radioactive contaminants - rock, radon in air, impurities
    - Emphasis on purification and shielding

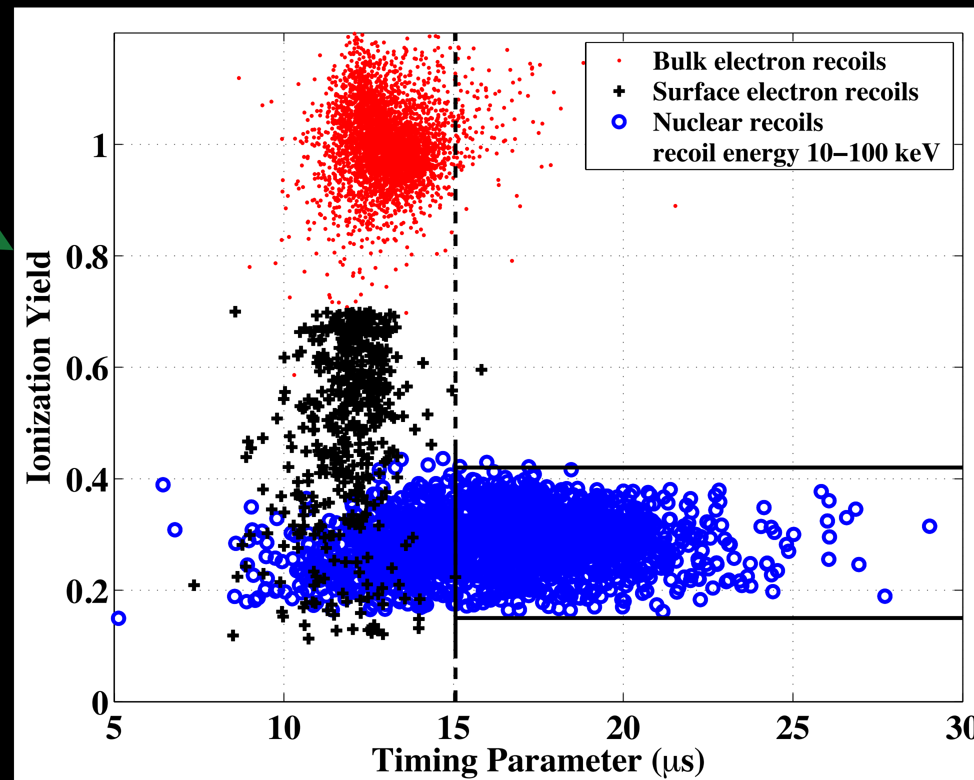

Background sources

- Cosmic rays are constantly streaming through
  - All experiments have to go underground to get away from cosmic rays
- Radioactive contaminants - rock, radon in air, impurities
  - Emphasis on purification and shielding
- The detector itself - steel, glass, detector components
  - Self-shielding to leave a clean inner region
  - Discrimination - can you tell signal from background (gamma rays, alphas, neutrons, etc)?

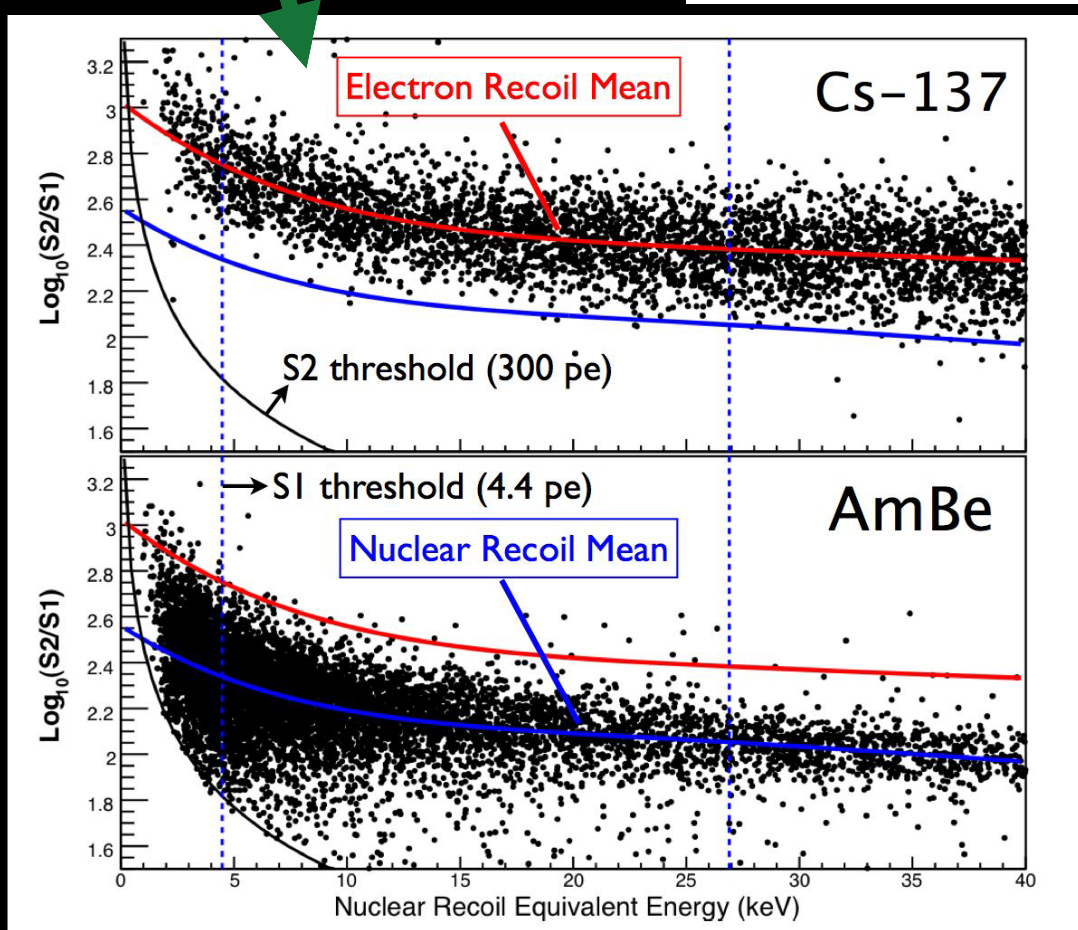

WIMPs and Neutrons
scatter from the
Atomic Nucleus
Photons and Electrons
scatter from the
Atomic Electrons

Electronic recoils (gammas) vs. nuclear recoils (WIMPs)

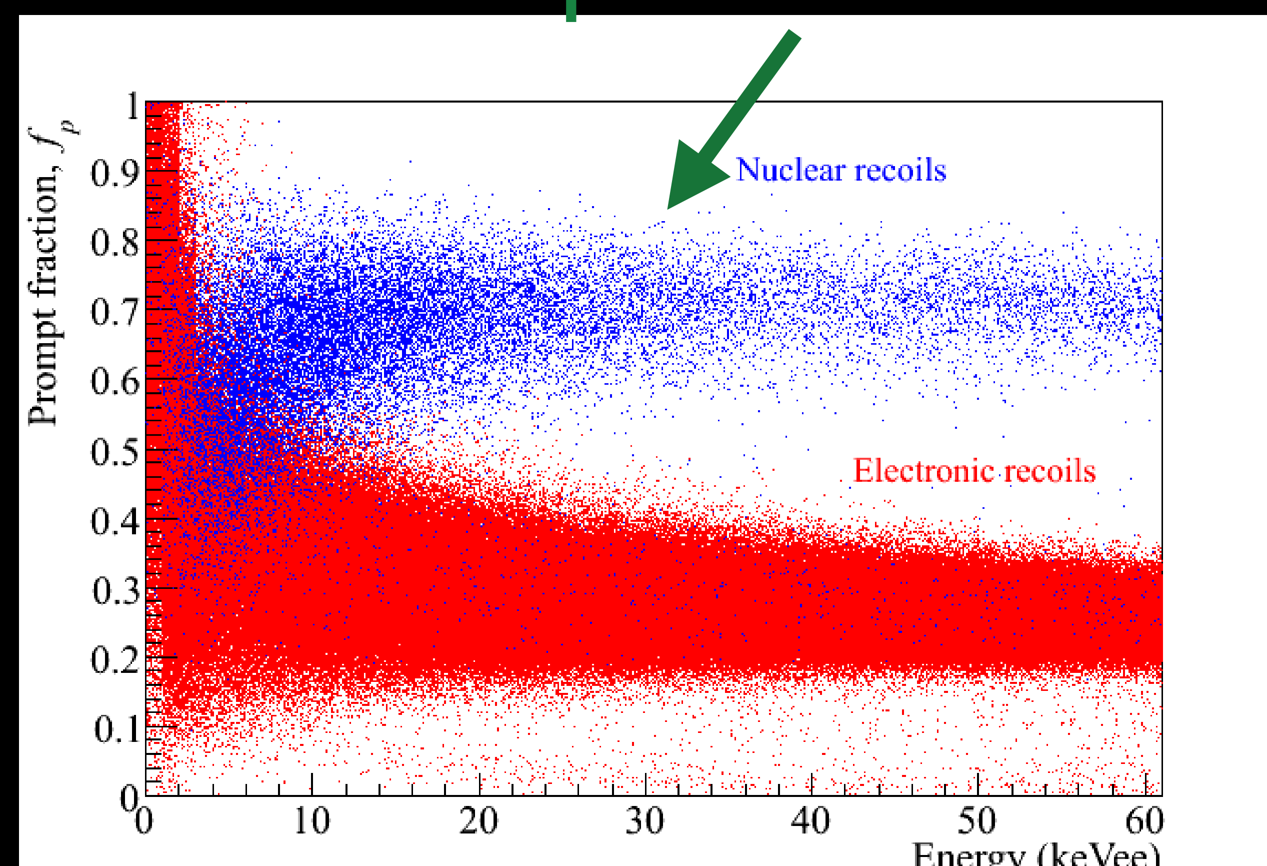
CDMS - Charge to heat



Xenon TPCs - Charge to light

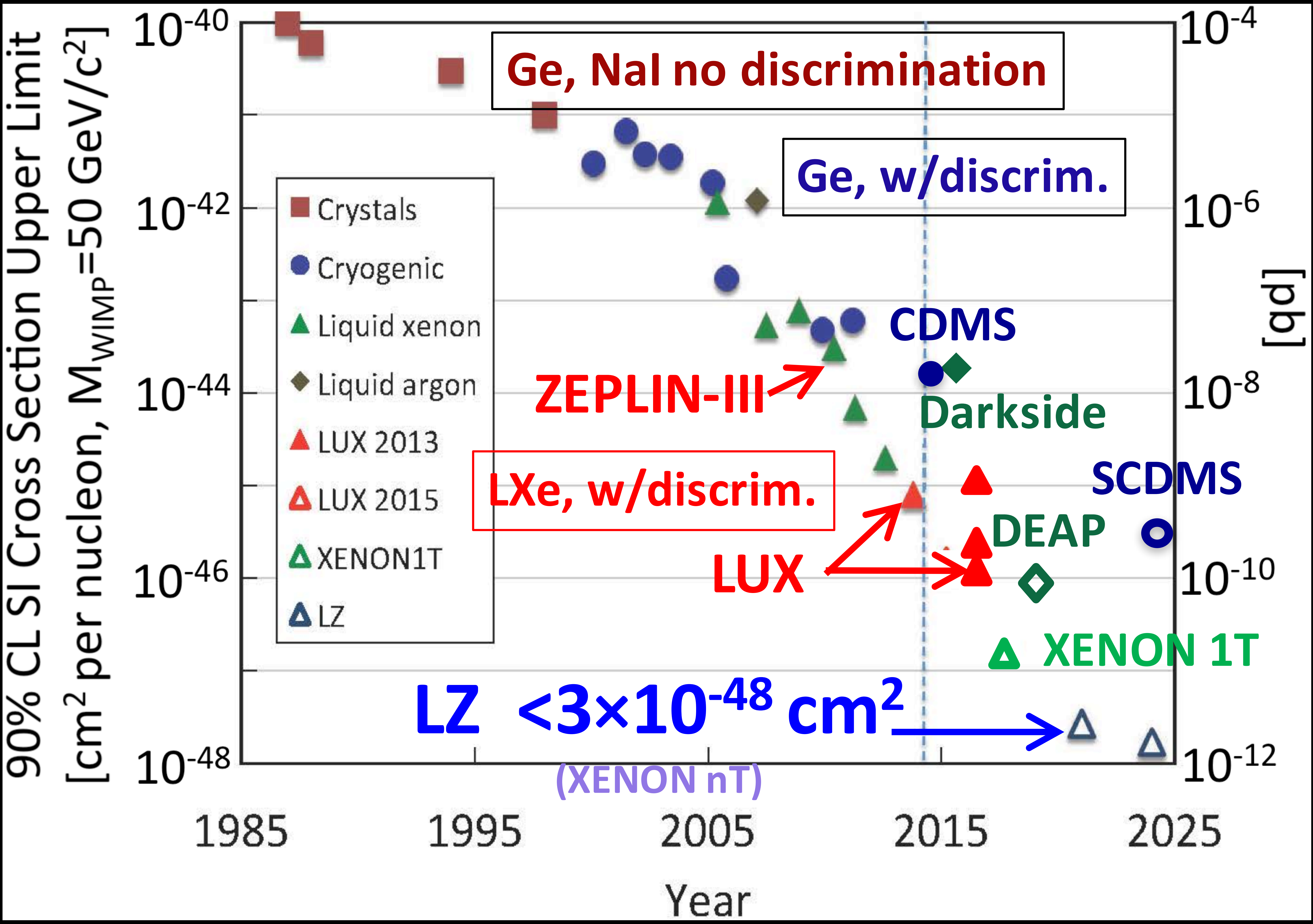


Argon - Pulse shape discrimination

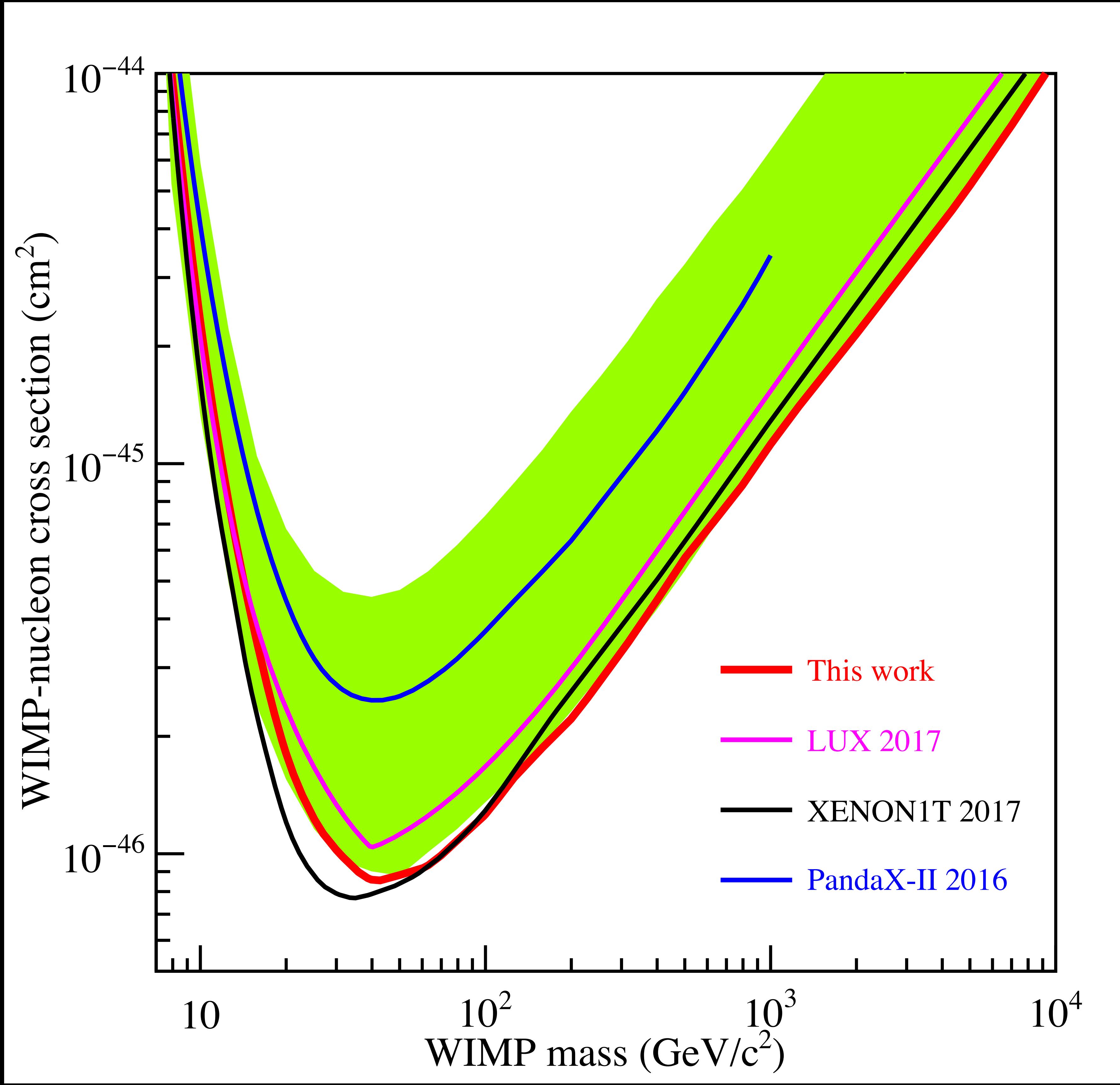


Background sources

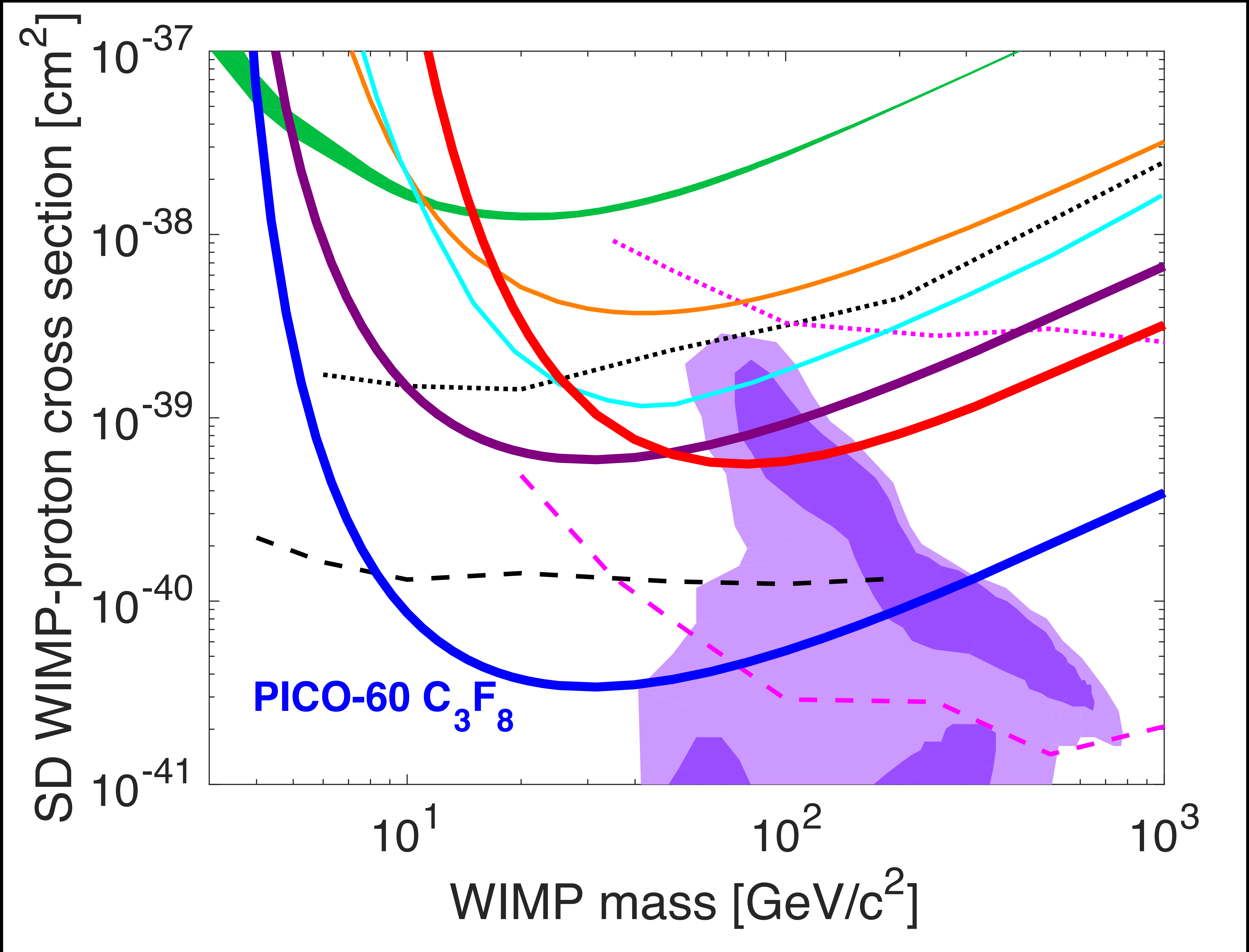
- Cosmic rays are constantly streaming through
    - All experiments have to go underground to get away from cosmic rays
- Radioactive contaminants - rock, radon in air, impurities
    - Emphasis on purification and shielding
- The detector itself - steel, glass, detector components
    - Discrimination - can you tell signal from background via some tag in the event itself?



90% CL SI Cross Section Upper Limit
[cm² per nucleon, M_WIMP=50 GeV/c²]
[pb]
Year
1985
1995
2005
2015
2025
10^-40
10^-42
10^-44
10^-46
10^-48
10^-4
10^-6
10^-8
10^-10
10^-12
Ge, NaI no discrimination
Ge, w/discrim.
Crystals
Cryogenic
Liquid xenon
Liquid argon
LUX 2013
LUX 2015
XENON1T
LZ
CDMS
ZEPLIN-III
Darkside
LXe, w/discrim.
SCDMS
DEAP
LUX
XENON 1T
LZ <3×10^-48 cm²
(XENON nT)



Panda-X and XENON1T recent results



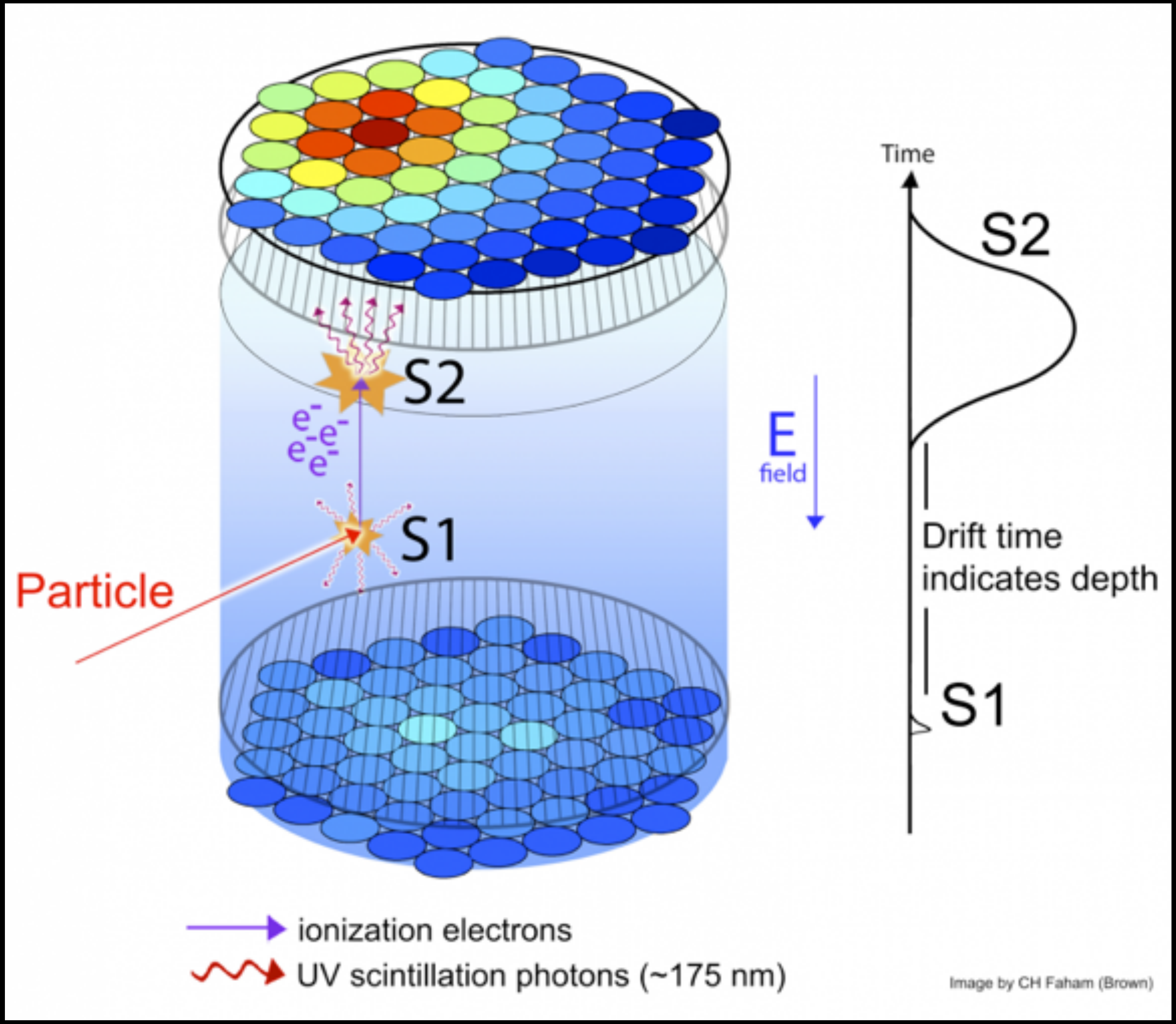
(with my old hat on) - PICO in SD space

LXe as Dark Matter Target

Problem	Solution	Liquid Xenon	
Extremely rare	Large mass	Very dense - 3 tonnes in 1 m^3	✓✓
Energy depositions of ~10 keV or below	Low energy thresholds	~60-70 electrons + photons / keV	✓✓
Backgrounds - Impurities	Purification	Noble gases are (mostly) easy to purify	✓
Backgrounds - Detector	Self shielding	Low MFP for ionizing radiation	✓✓✓
Backgrounds - Internal/Detector	Discrimination	Charge to light ratio gives particle ID	✓

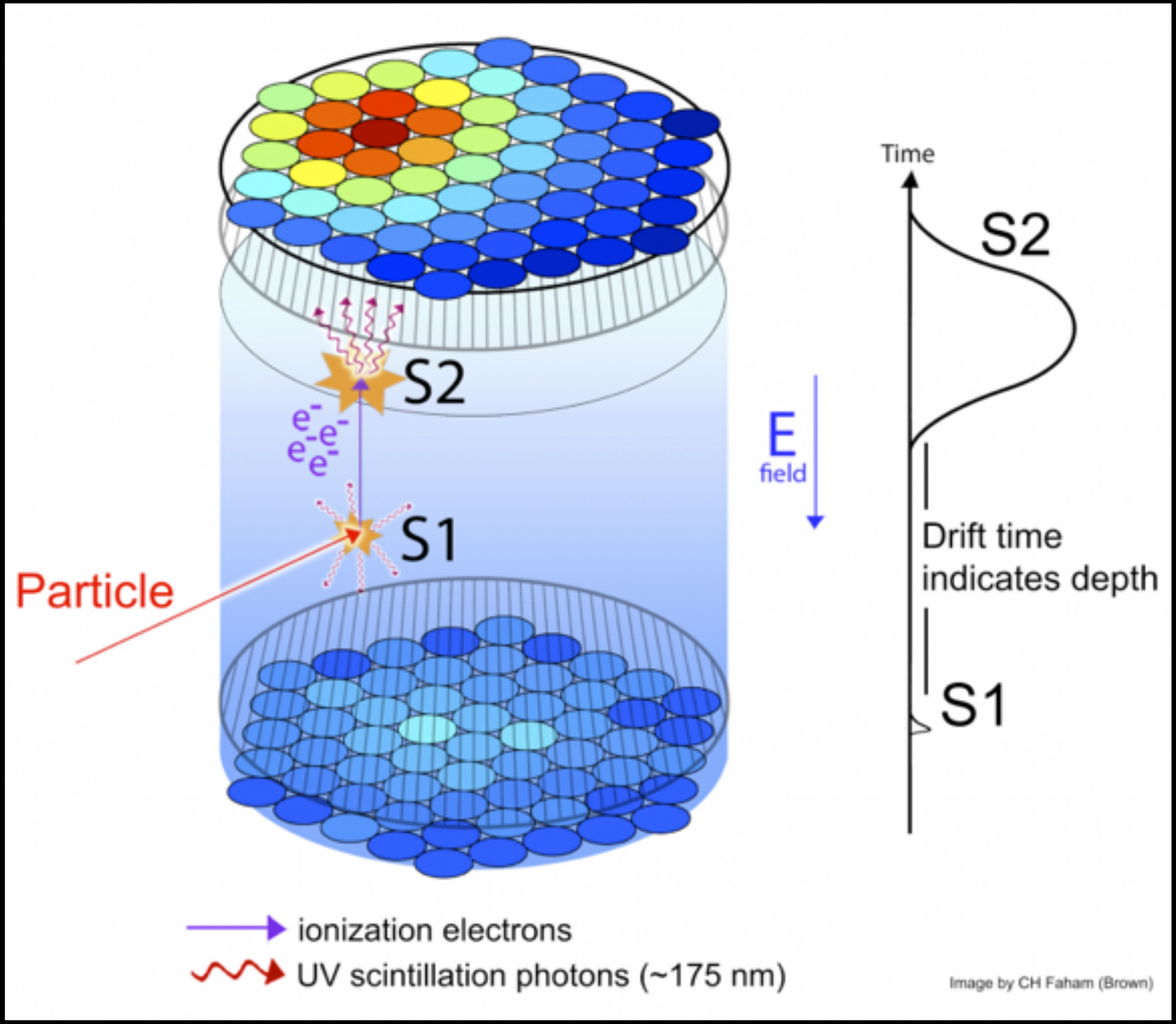
Two phase Xenon Detectors

- Interaction in the xenon creates:
  - Scintillation light (~10 ns) - called S1
  - ionization electrons
- Electrons drift through electric field to liquid/gas surface
  - Extracted into gas and accelerated creating proportional scintillation light - called S2

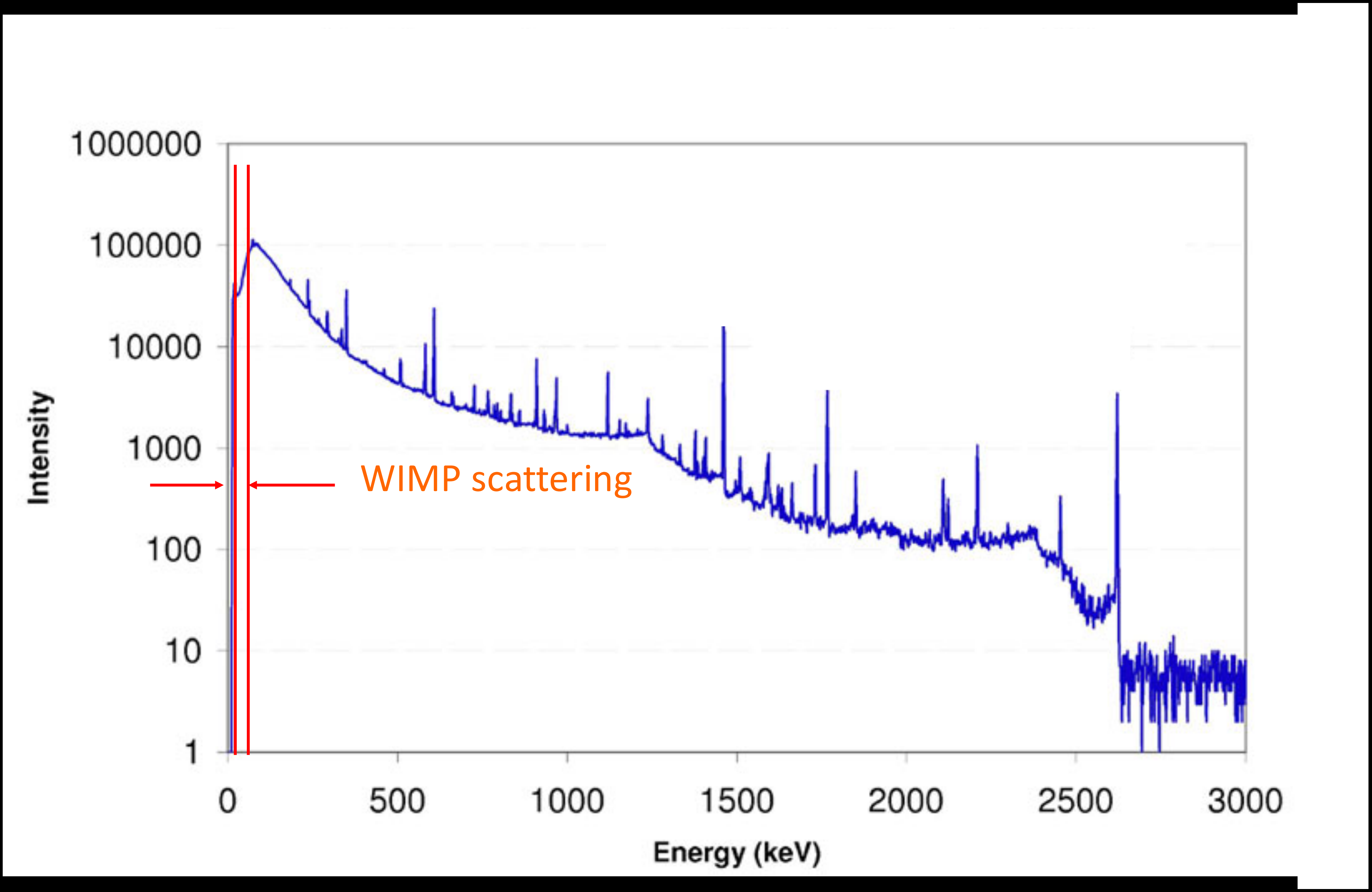


Two phase Xenon Detectors

- Excellent 3D reconstruction (~mm)
  - Z position from S1-S2 timing
  - XY position from hit pattern of S2 light
  - Allows for self shielding, rejection of edge events
- Ratio of charge (S2) to light (S1) gives particle ID
  - Better than 99.5% rejection of electron recoil events

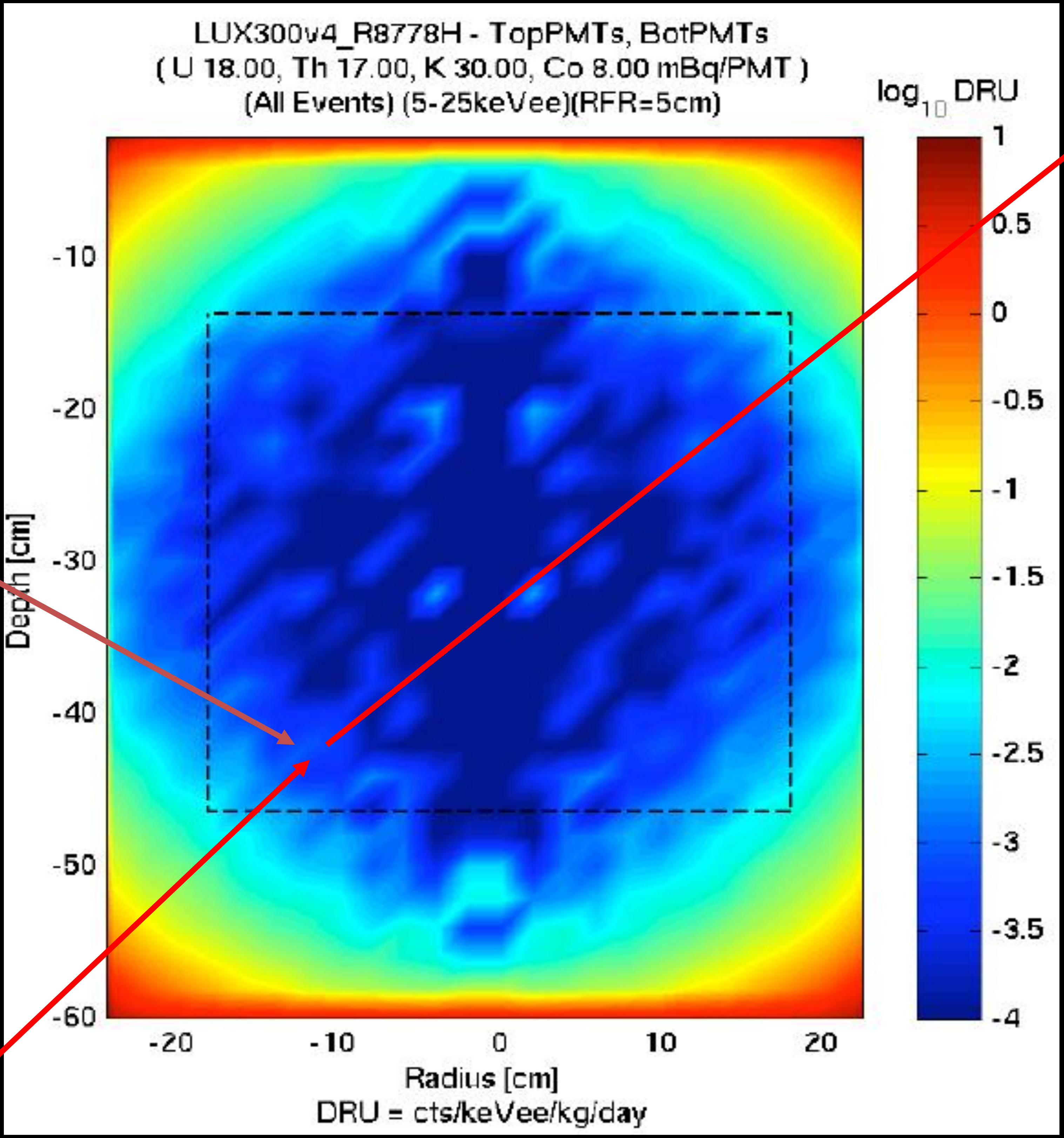


Self shielding is powerful



Self shielding is powerful

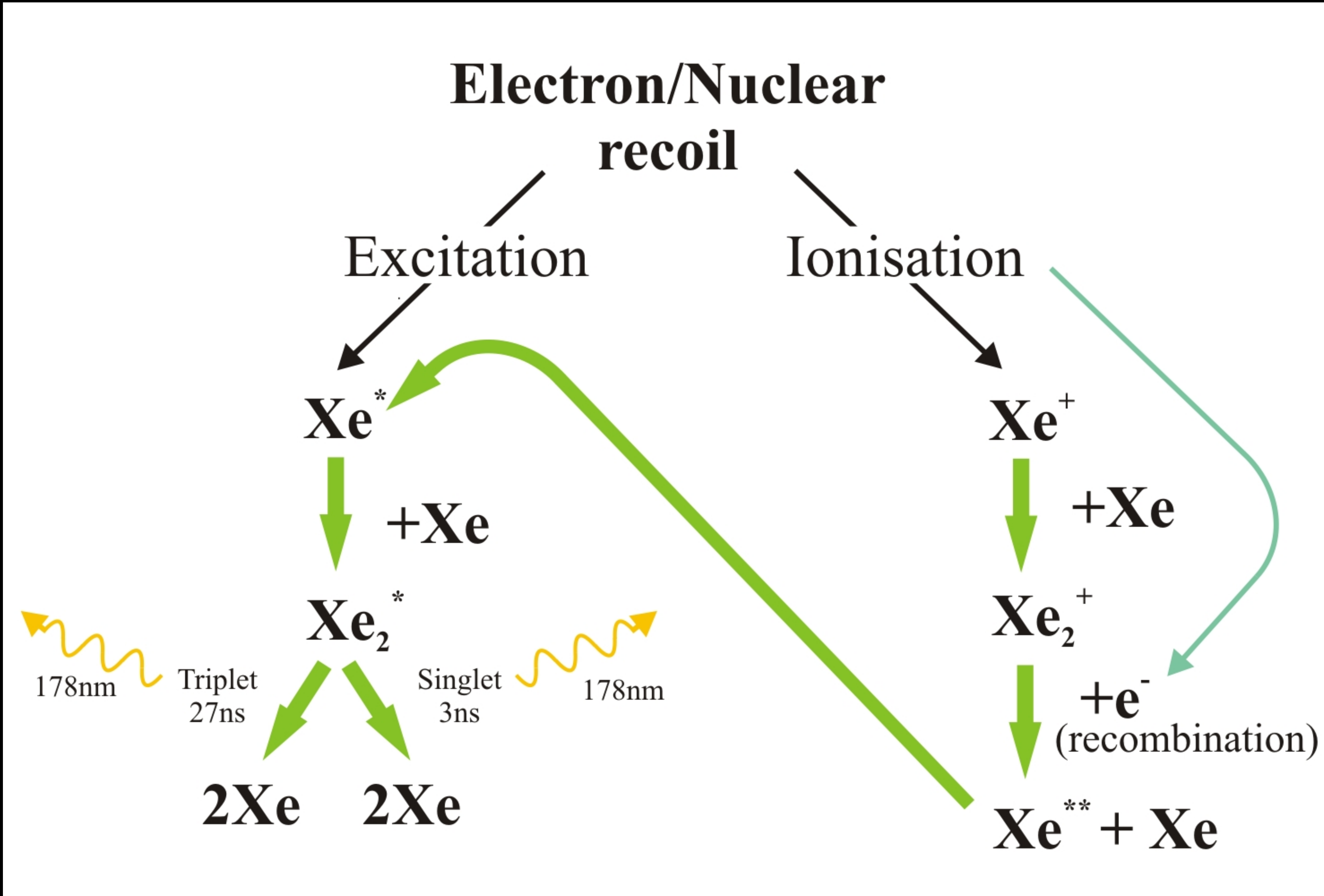
~keV energy deposit



Must cross full volume without interacting

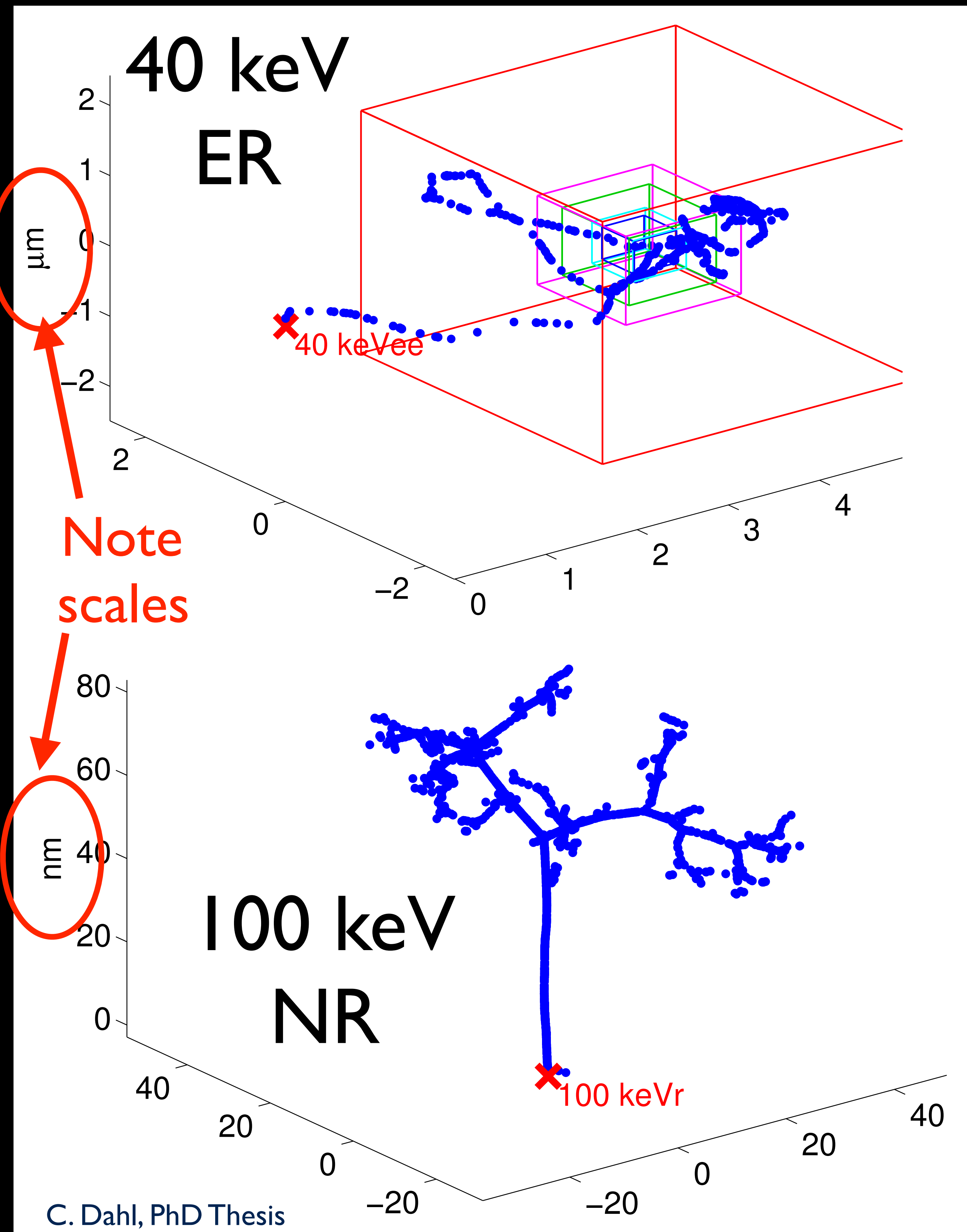
~MeV gamma

Some LXe physics



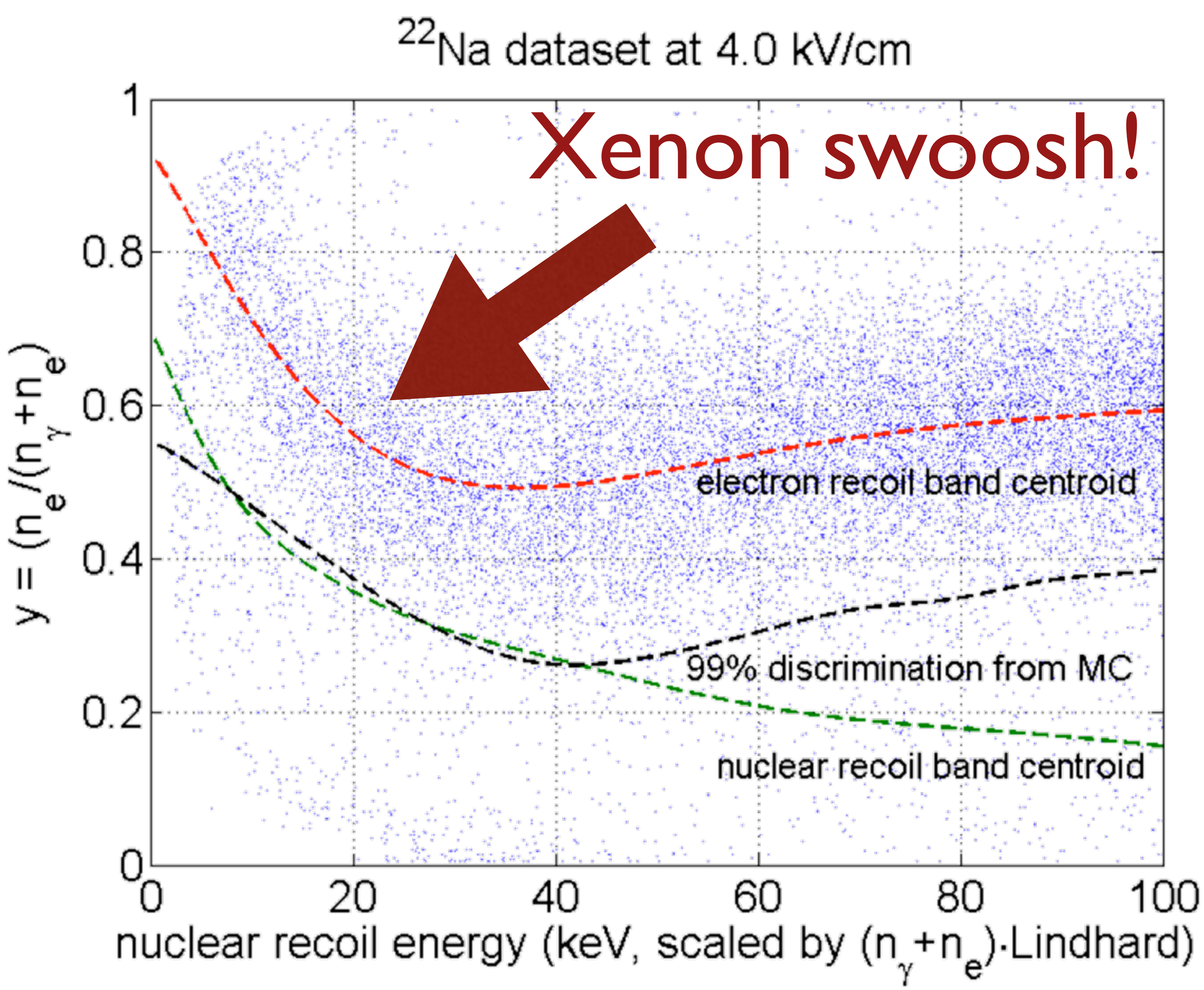
Some LXe physics

- Significant difference between ER and NR tracks
- ER lead to more signal than NR
  - More NR energy goes into heat and is lost
    - Lindhard factor, L_{eff}, Quenching factor
  - Two energy scales keV_{ee} and keV_{nr}
- Leads to different behavior with field
- Also leads to ER/NR discrimination



Some LXe physics (h.t. Eric Dahl)

- General thinking (including my own unless I'm being careful about it) is that ER/NR discrimination depends mainly on track density
  - This is not true for LXe! and in fact, LXe would not be nearly as powerful if that were the case



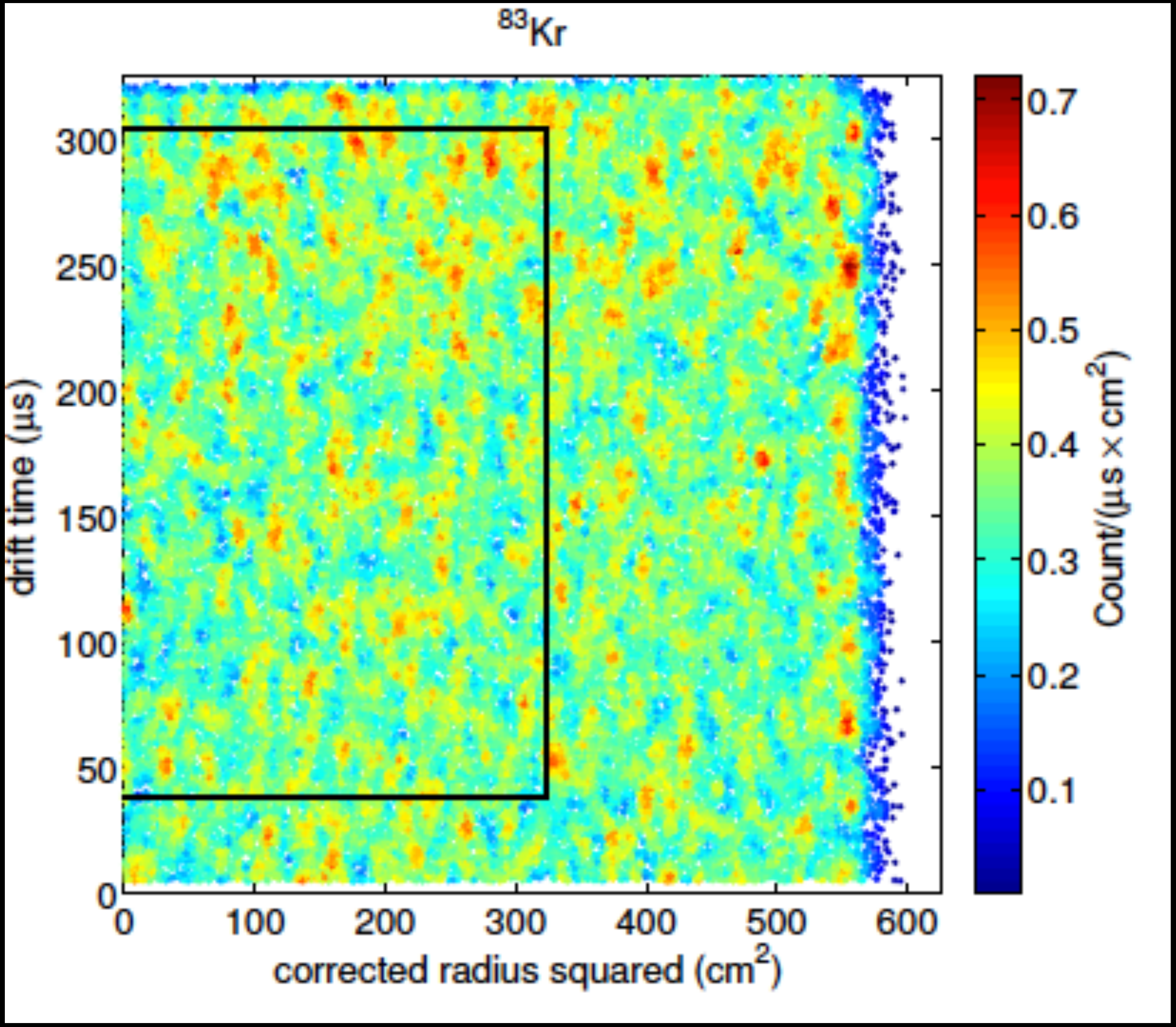
surement below 20 keVr, we see a striking increase in y for electron recoils with E $\lesssim$ 35 keVr (and to a lesser extent nuclear recoils with E $\lesssim$ 20 keVr). The origin of this is not yet understood, but its importance in enabling discrimination to below 10 keVr cannot be overstated. The WIMP sensitivity of Xe

Nucl. Instrum. Meth. A **579**:451-453, 2007

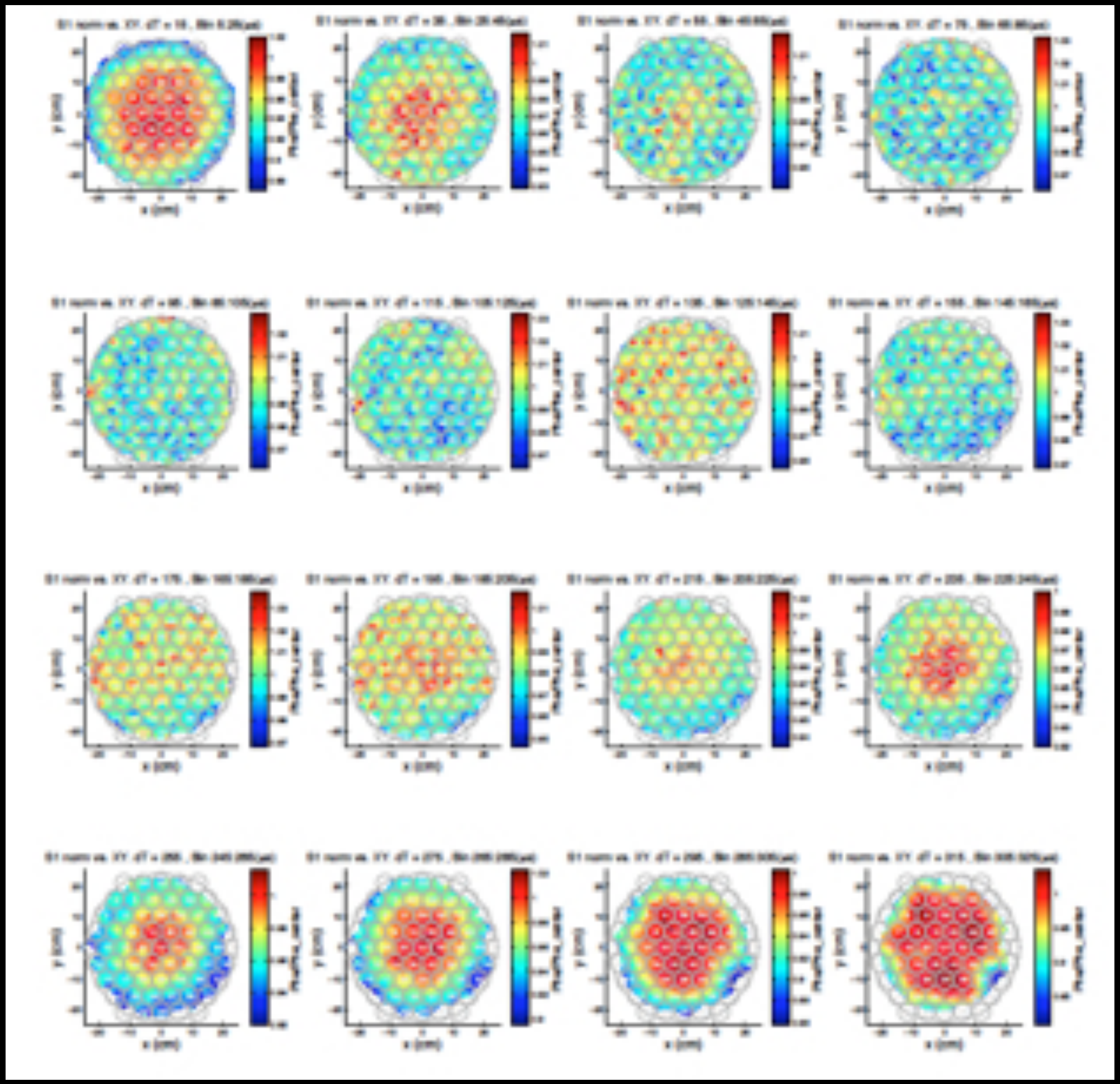
Requires calibration

- LUX has really done great work here
  - Kr-83m - Over 1e6 events spread uniformly throughout detector

Fiducial volume determination



Position-based S1 corrections



Requires calibration

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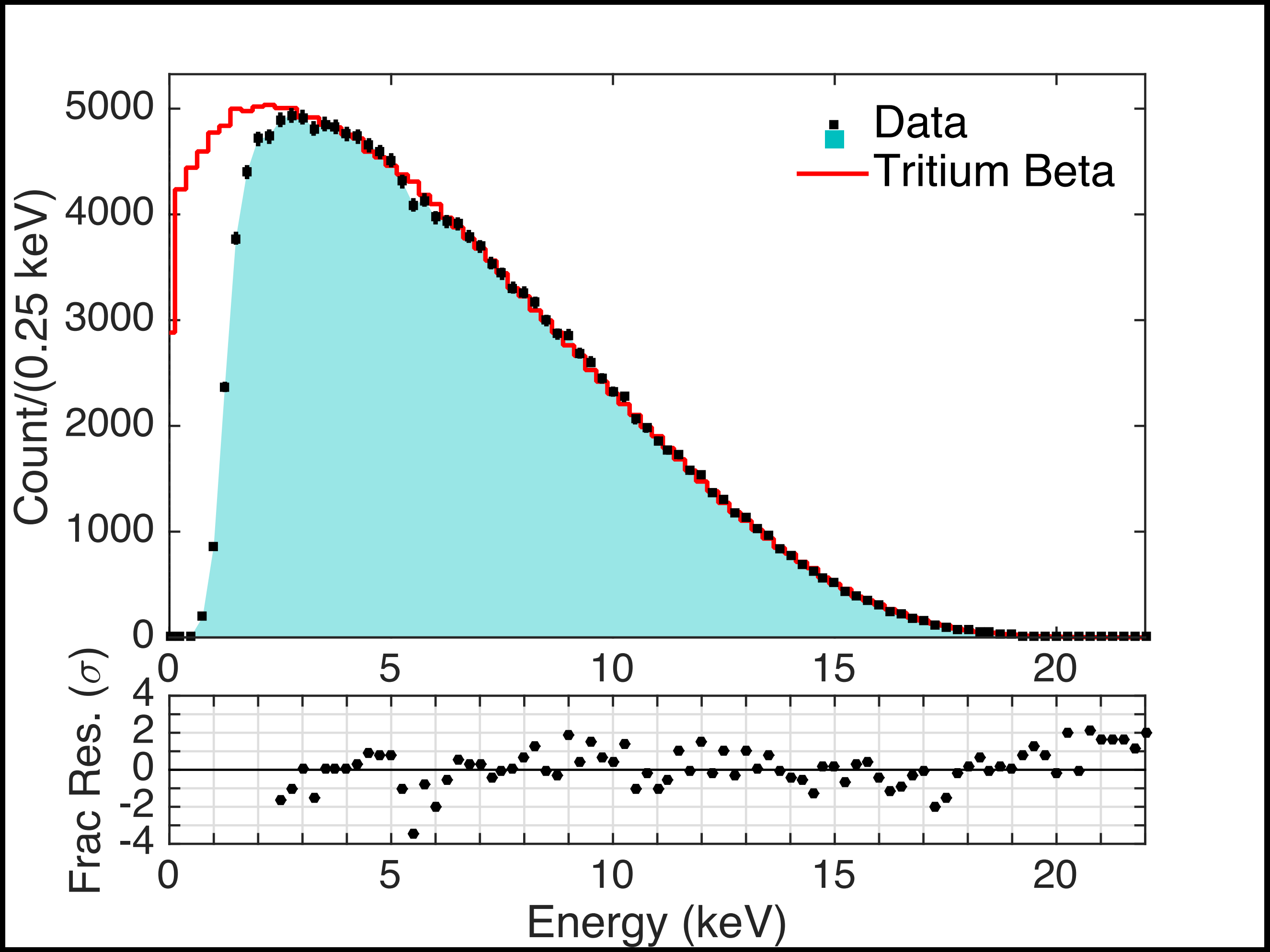
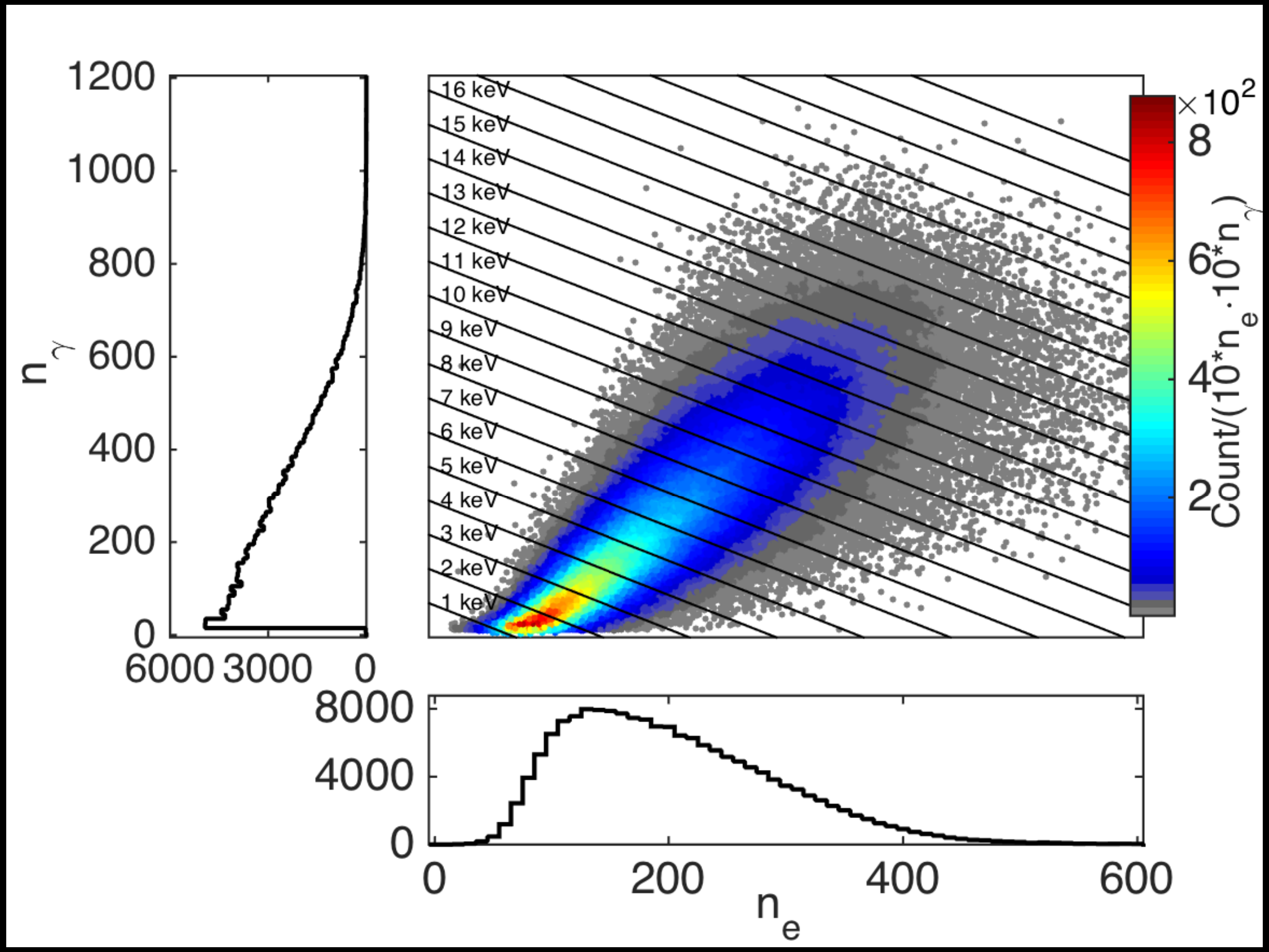
  - Tritiated methane (CH3T) - to measure low energy ER band

Low energy ER



Measured in both light and charge



Requires calibration

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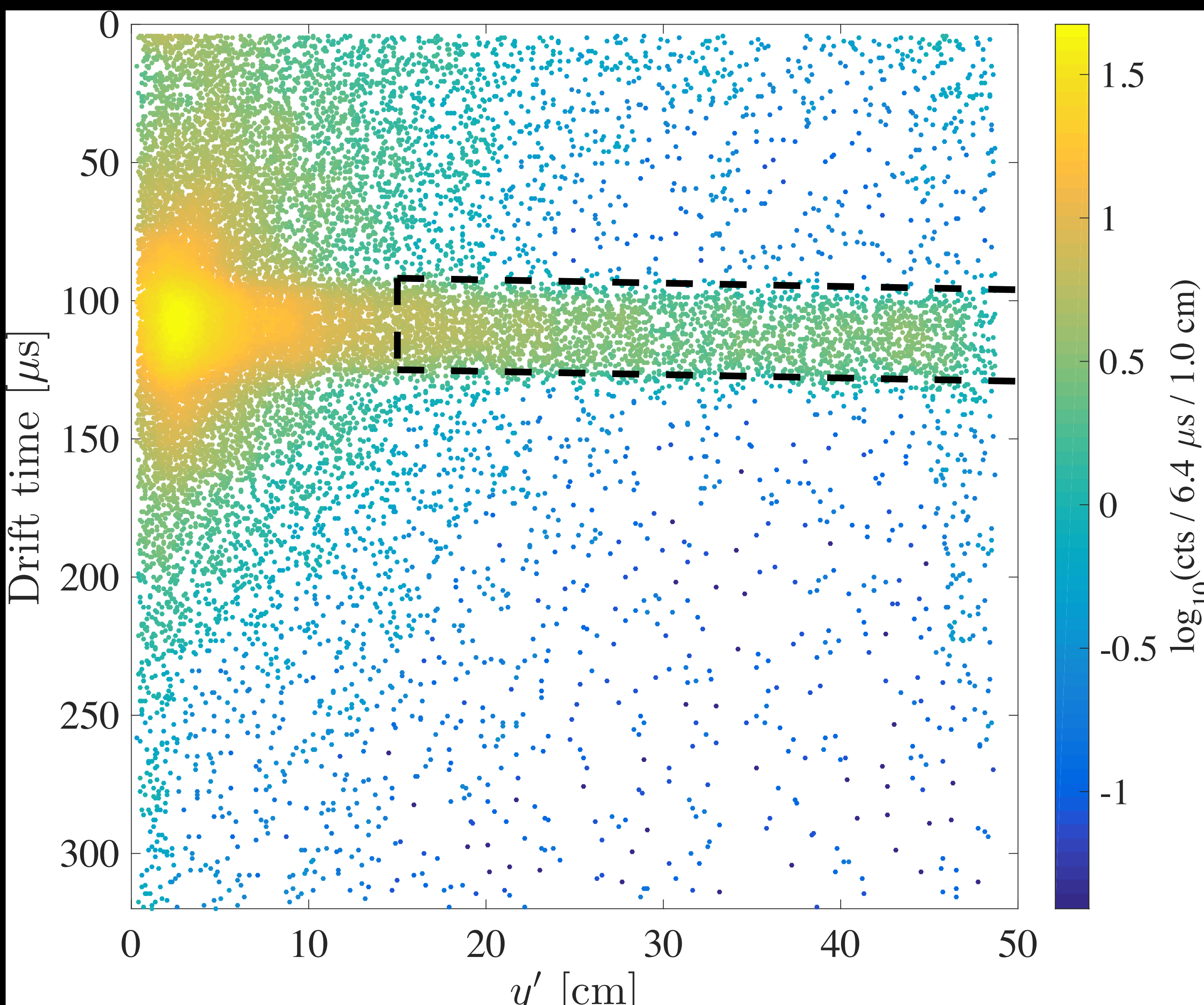
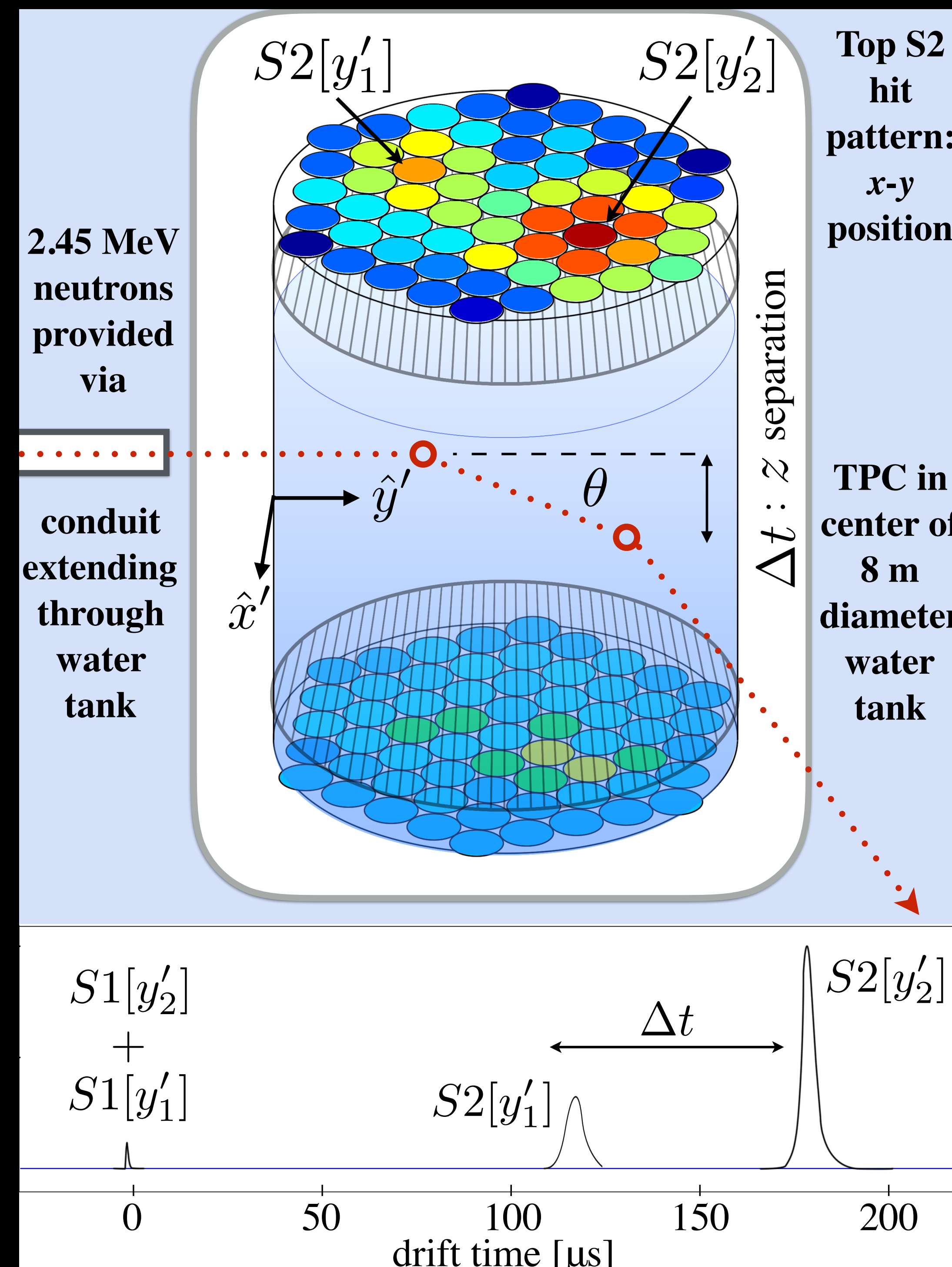
  - DD neutron generator to measure NR yields





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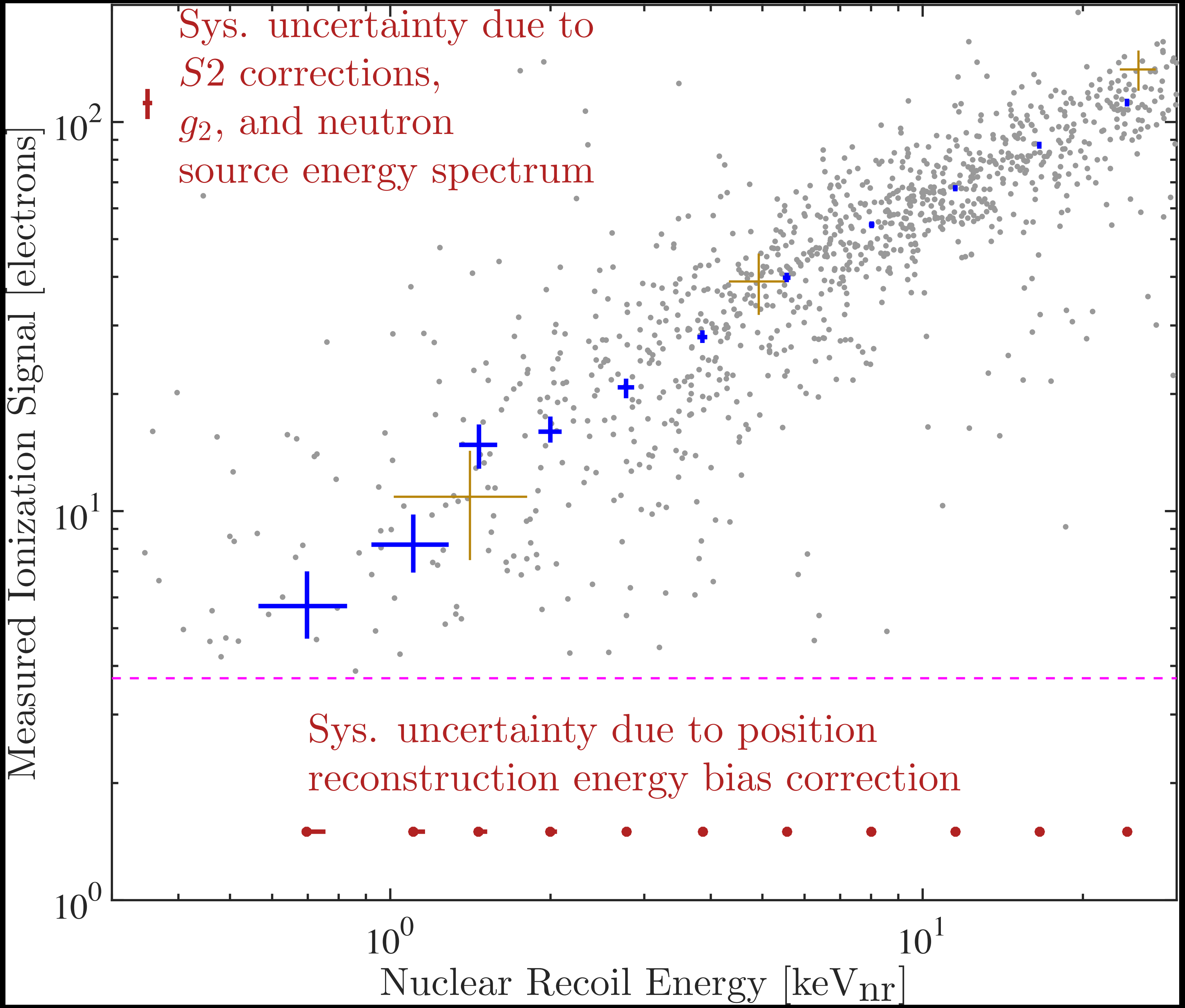
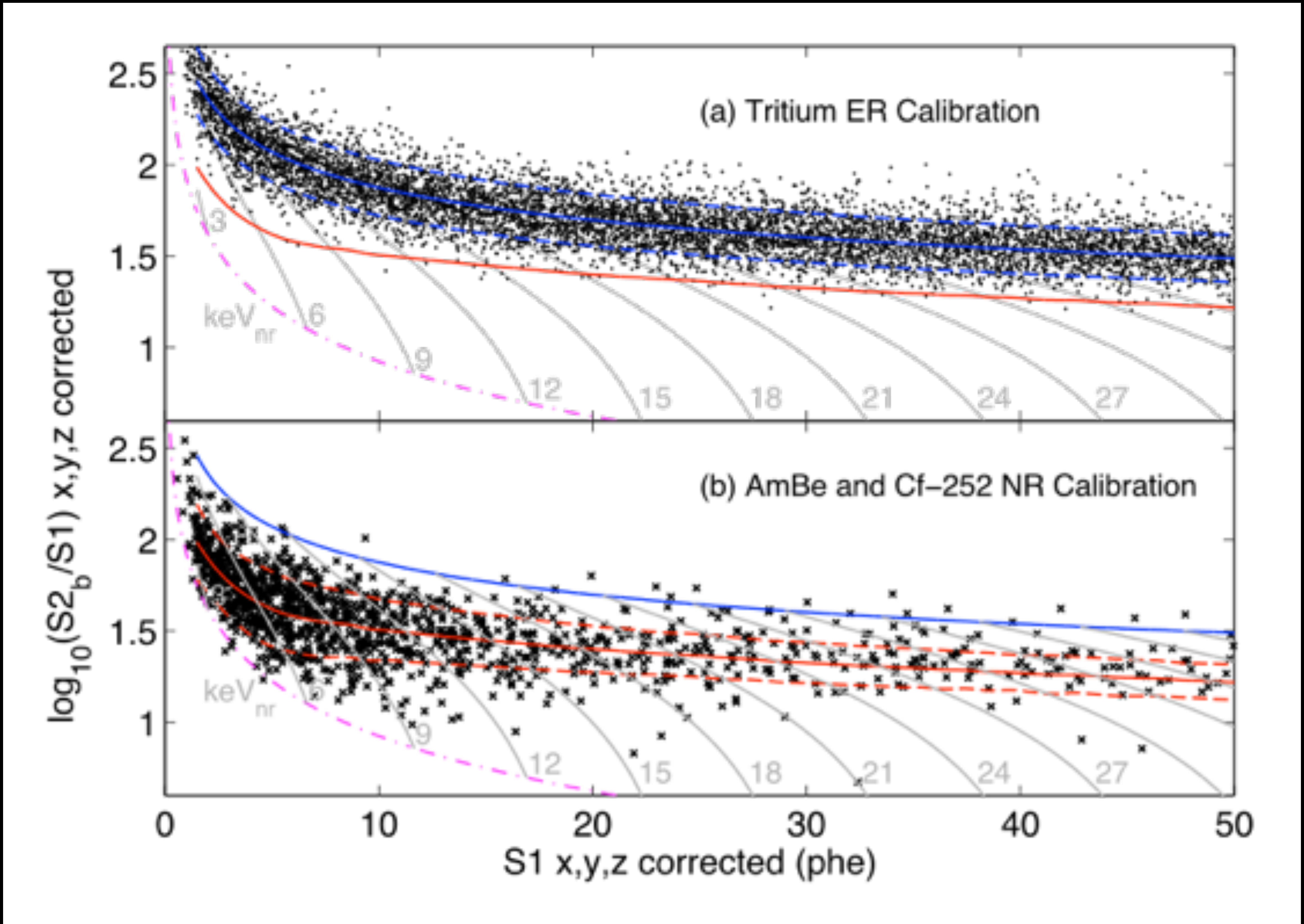
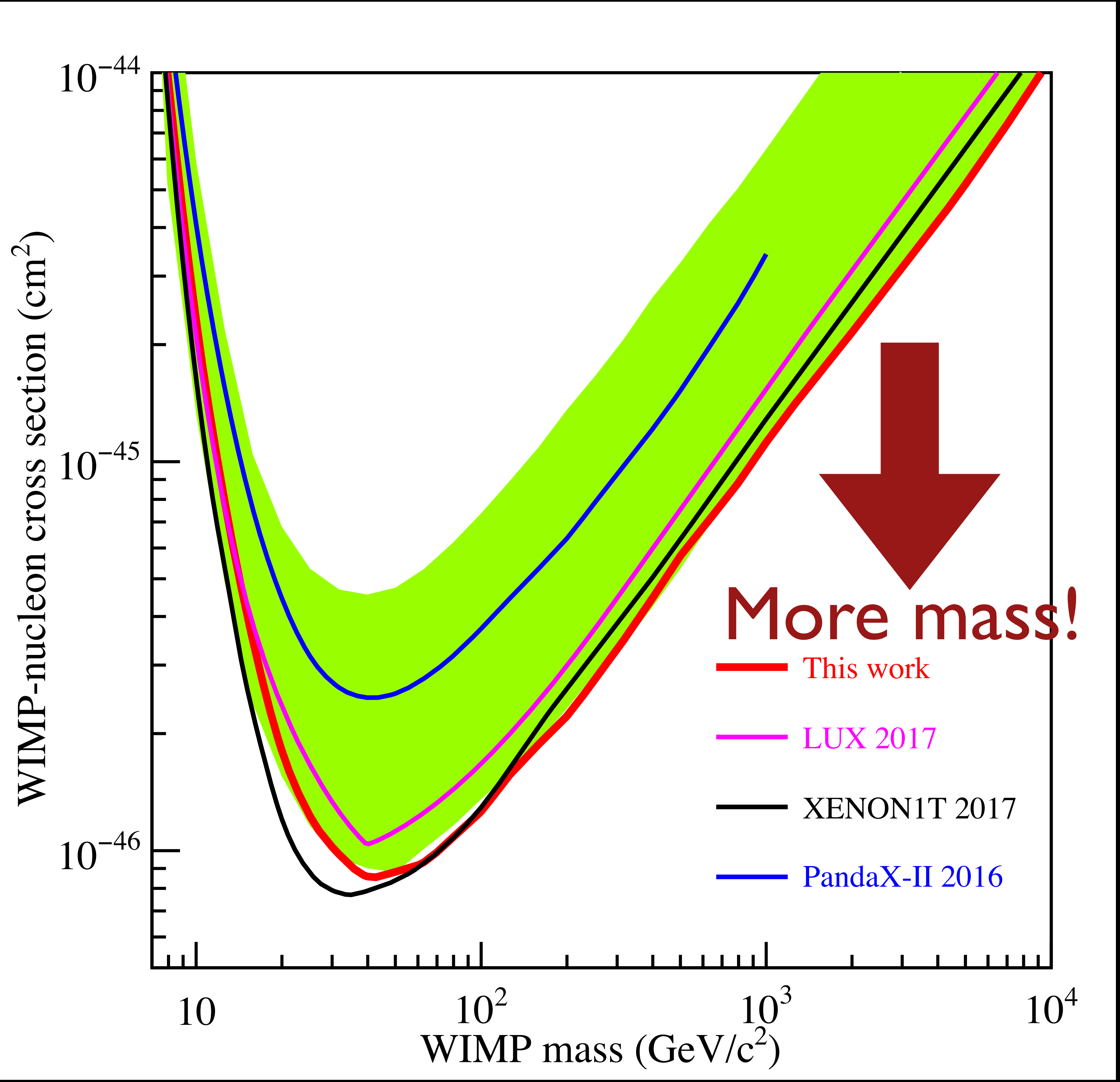


Leads to background rejection



Grey contours indicate lines of constant energy



LUX - 100 kg (active)
PandaX-II - 329 kg (fid)
Xenon1T - 1 tonne (fid)

LZ = LUX + ZEPLIN

38 Institutions, 217 People

Black Hills State University
Brookhaven National Laboratory (BNL)
Brown University
Fermi National Accelerator Laboratory (FNAL)
Kavli Institute for Particle Astrophysics and Cosmology (KIPAC)
Lawrence Berkeley National Laboratory (LBNL)
Lawrence Livermore National Laboratory (LLNL)
Northwestern University
Pennsylvania State University
SLAC National Accelerator Laboratory
South Dakota School of Mines and Technology
South Dakota Science and Technology Authority (SDSTA)
STFC Rutherford Appleton Laboratory (RAL)
Texas A&M University
University at Albany (SUNY)
University of Alabama
University of California (UC), Berkeley
University of California (UC), Davis
University of California (UC), Santa Barbara
University of Maryland
University of Massachusetts
University of Michigan
University of Rochester
University of South Dakota
University of Wisconsin-Madison
Washington University in St. Louis
Yale University

Center for Underground Physics (Korea)
Imperial College London (UK)
LIP Coimbra (Portugal)
MEPhI (Russia)
STFC Rutherford Appleton Laboratory (UK)
University College London (UK)
University of Bristol (UK)
SUPA, University of Edinburgh (UK)
University of Liverpool (UK)
University of Oxford (UK)
University of Sheffield (UK)

Scale Up ≈50 in Fiducial Mass

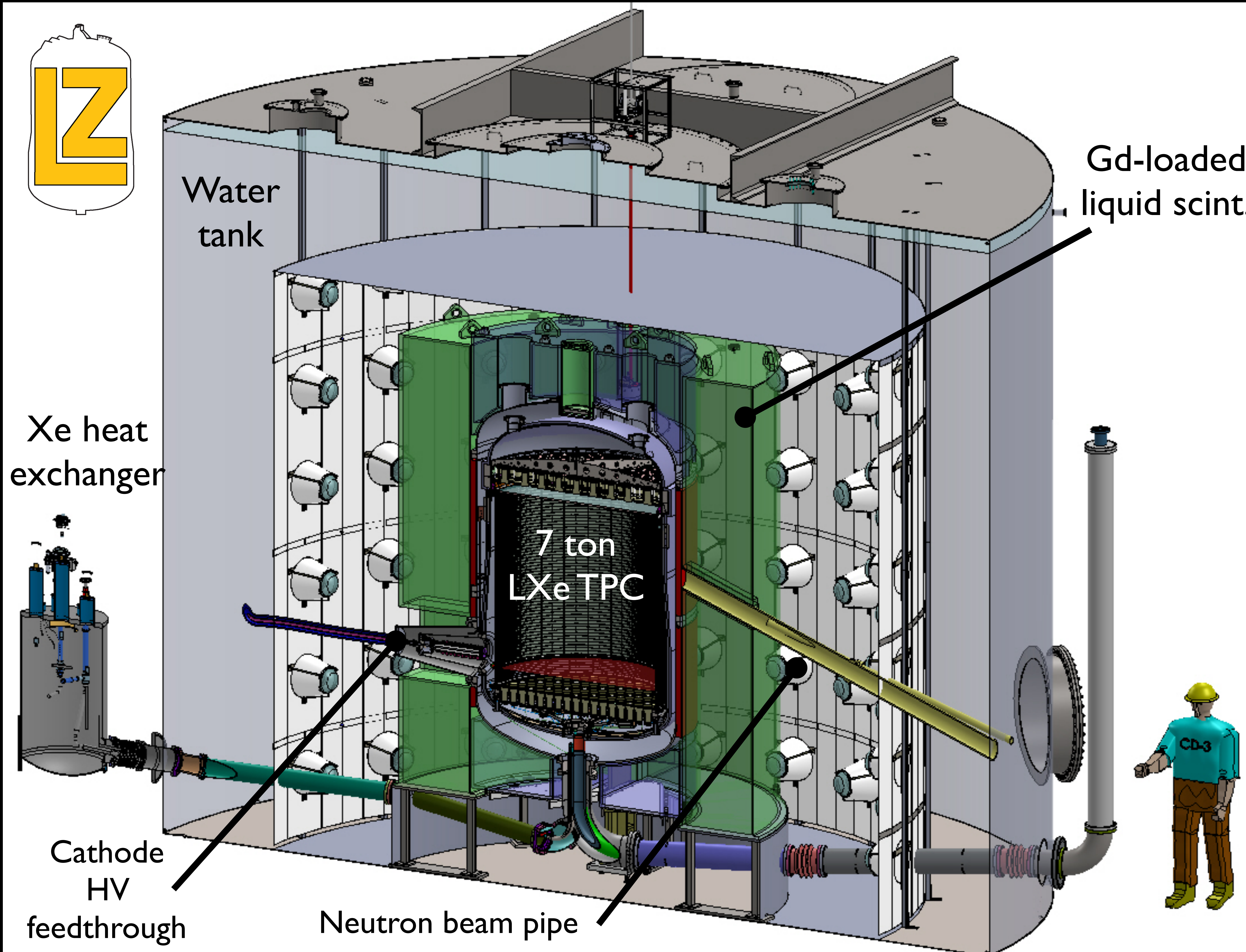
LZ

Total mass – 10 T
WIMP Active Mass – 7 T
WIMP Fiducial Mass – 5.6 T

Sanford Underground Research Facility

Davis Cavern 1480 m
(4200 mwe)
LUX Water Tank

LZ Here

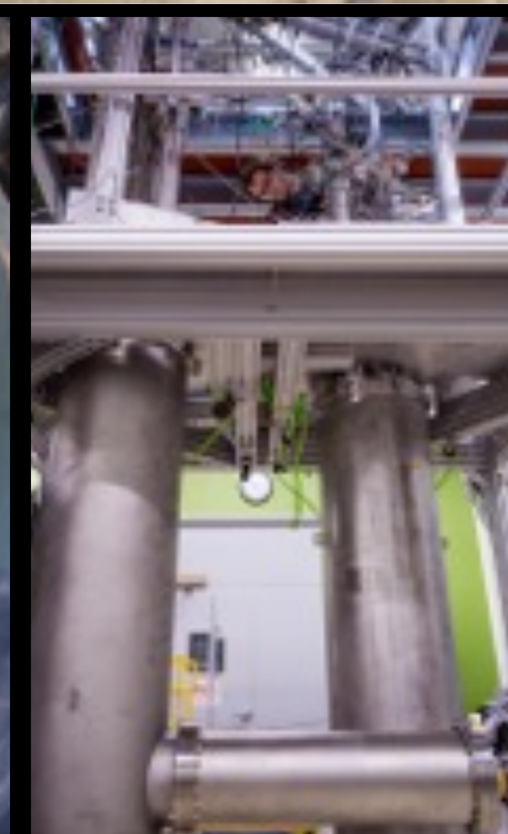

Water
tank
Gd-loaded
liquid scint.
Xe heat
exchanger
7 ton
LXe TPC
CD-3
Cathode
HV
feedthrough
Neutron beam pipe

LZ design notes

- More mass (x50 more than LUX, x6 more than Xenon1T design)
  - 494 3" PMTs on TPC
- Significant HV/grid engineering (no xenon experiment has achieved HV goals so far)
  - Requirement: 50 kV   Goal: 100 kV
- Sophisticated veto system - maximizes fiducial volume
  - LXe "skin" - 93 1" PMTs + 38 2" PMTs
  - 120 outer detector PMTs
- Radioactivity, radioactivity, radioactivity!

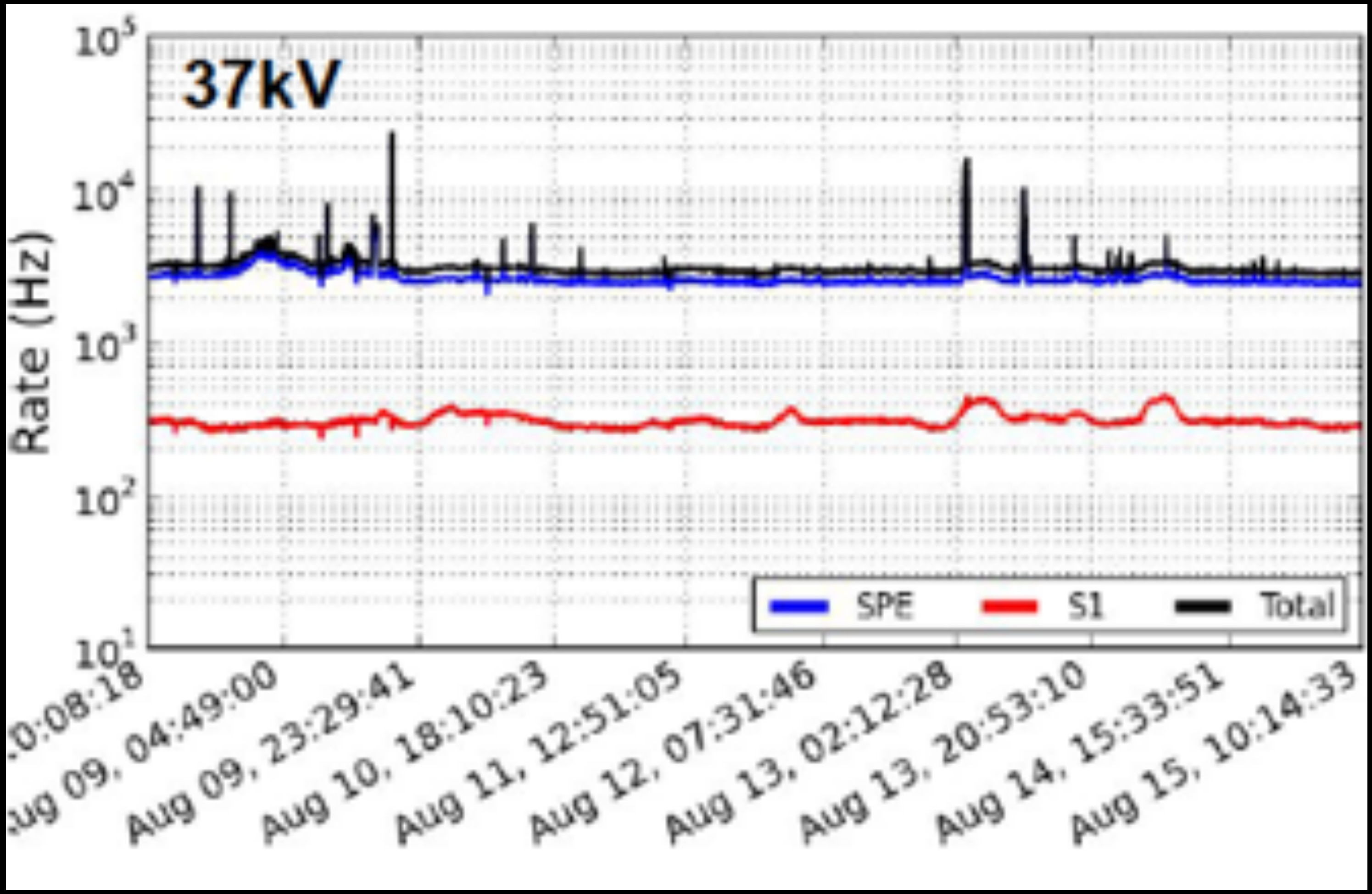
System test at SLAC

- Main test platform for LZ
  - Same cryogenics/control
- Phase 1 (ongoing)
  - Full LZ fields in scaled prototype TPC
    - Can HV be achieved with sparking or light emission?
  - Prototype circulation
    - LZ architecture and compressor
- Phase II will test grids

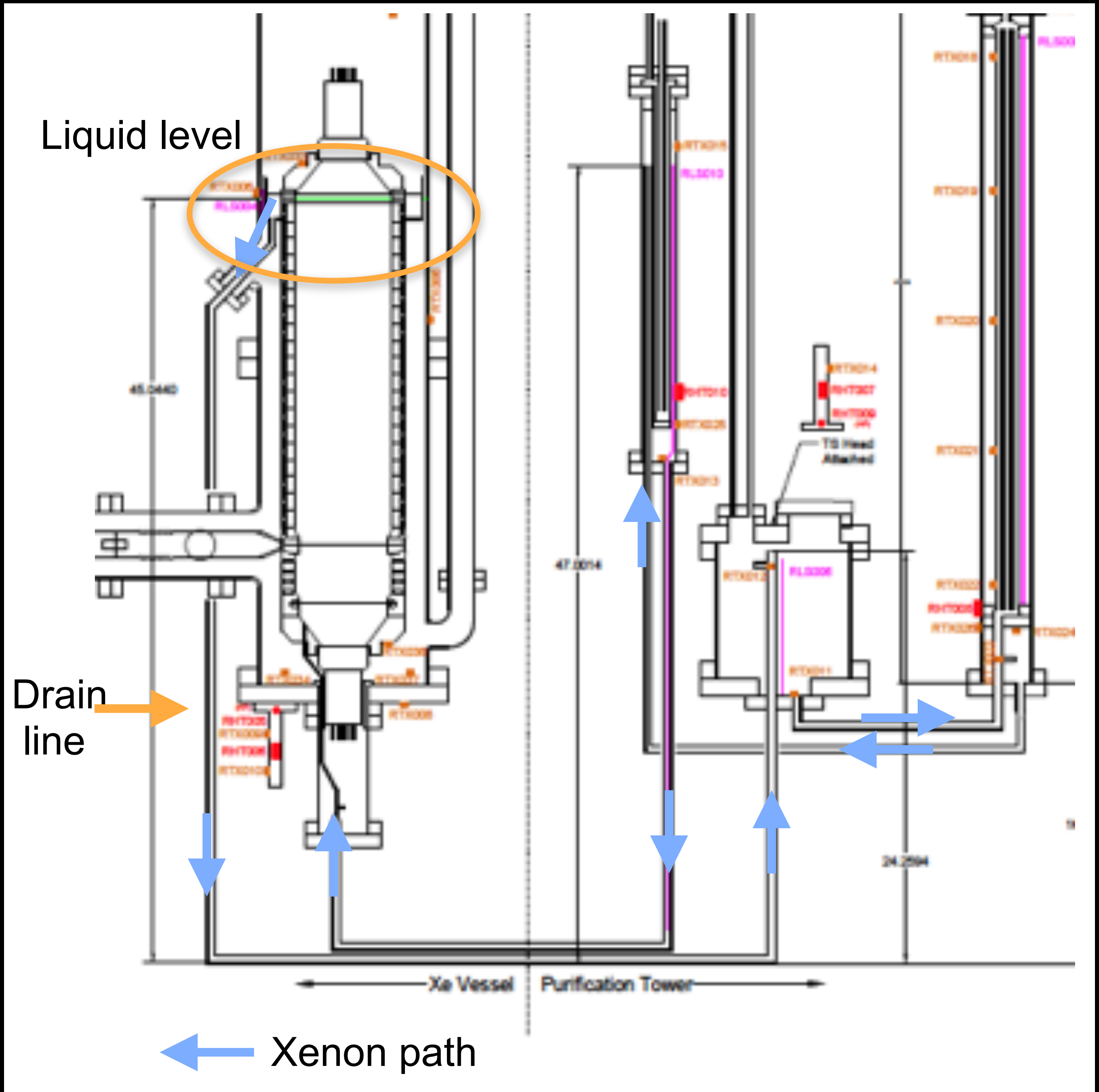


HV tests at SLAC

- HV of 20% above requirement has been achieved for cathode and extraction region!
  - Next step is to achieve goals



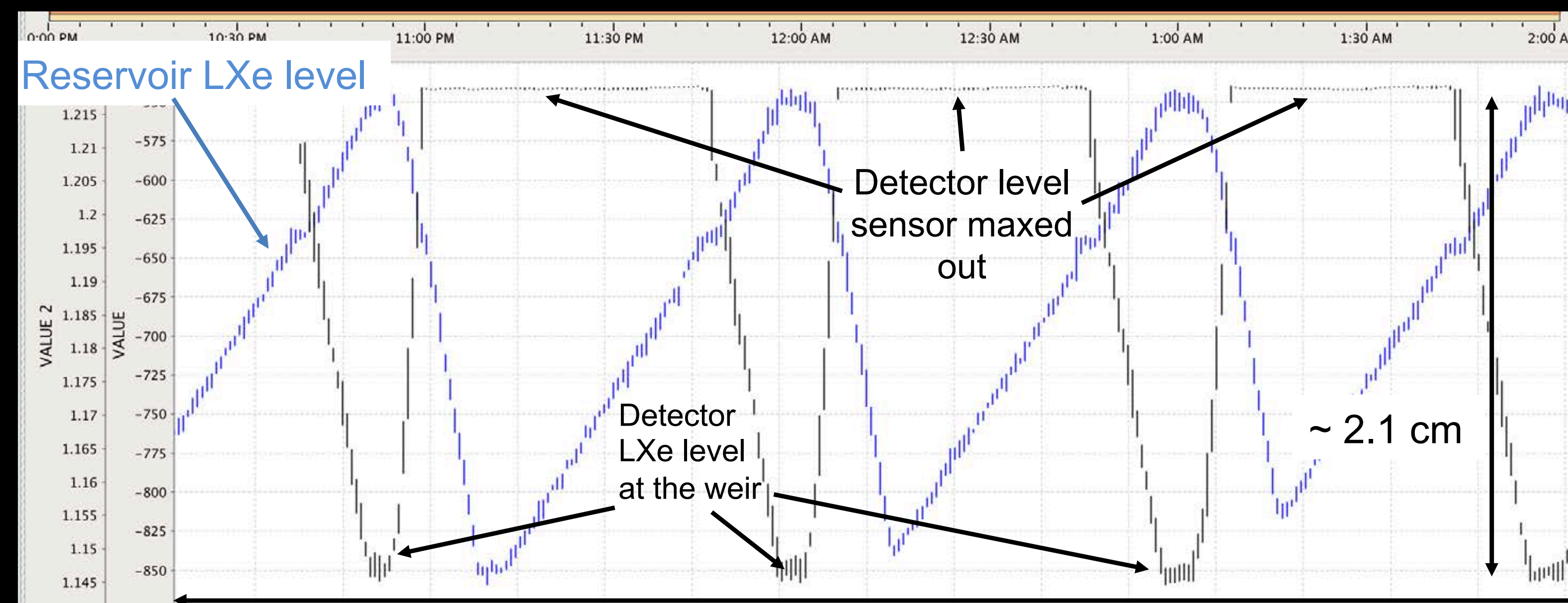
Circulation tests at SLAC



- Liquid meant to flow over a weir into a transfer line to an external heat exchanger and out to gas loop

Circulation tests at SLAC

- Initial runs did not achieve stable liquid level
  - Bad for S2 resolution
- Boiling in the transfer line
  - Added active cooling to drain line
  - Gas vent to drain line



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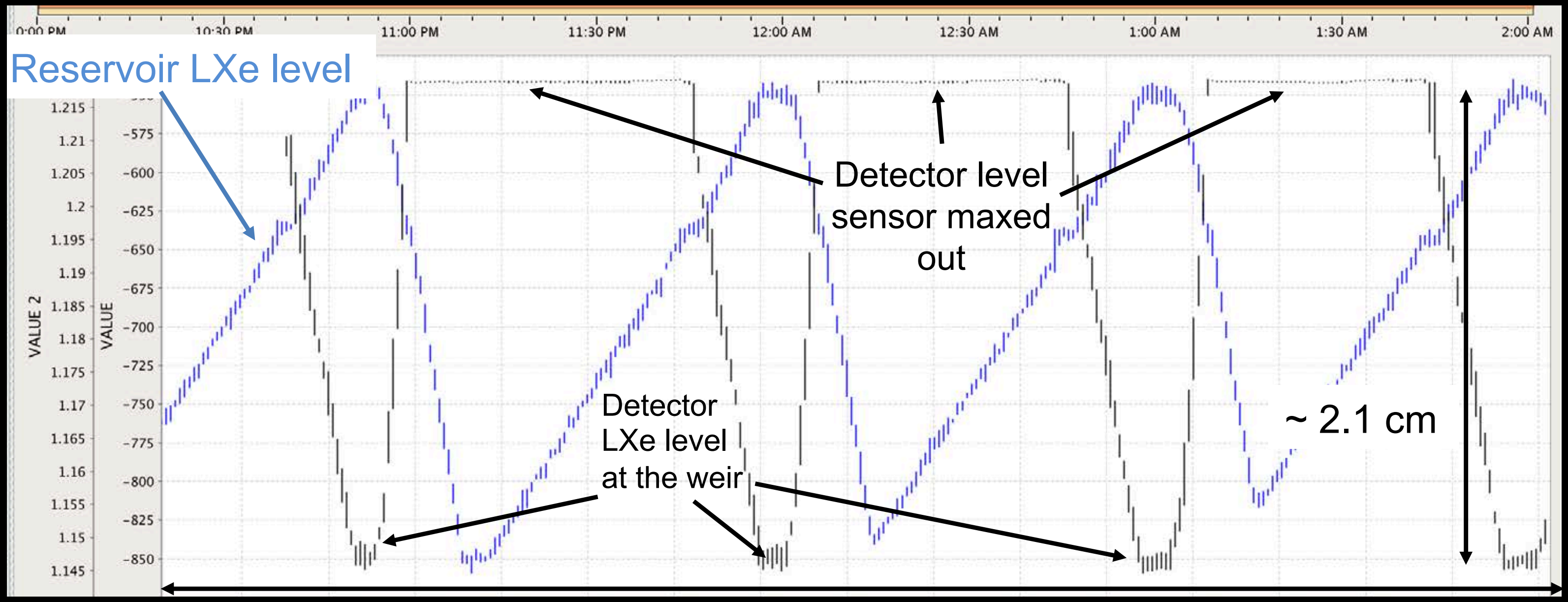
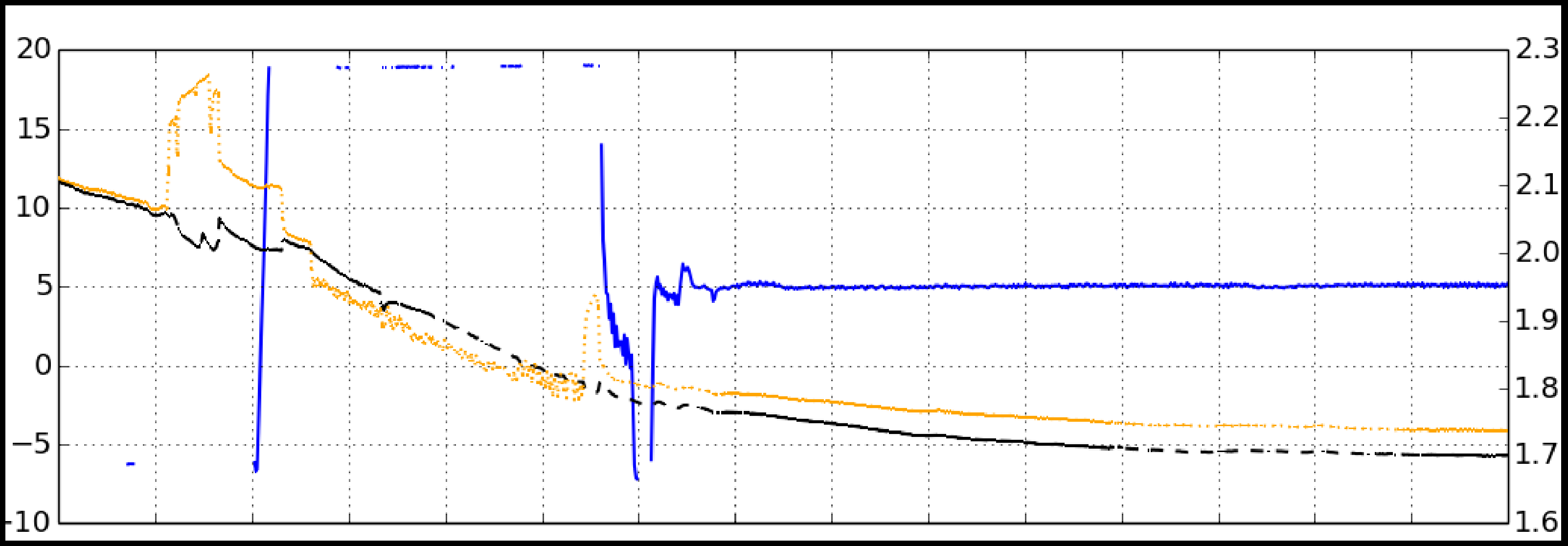
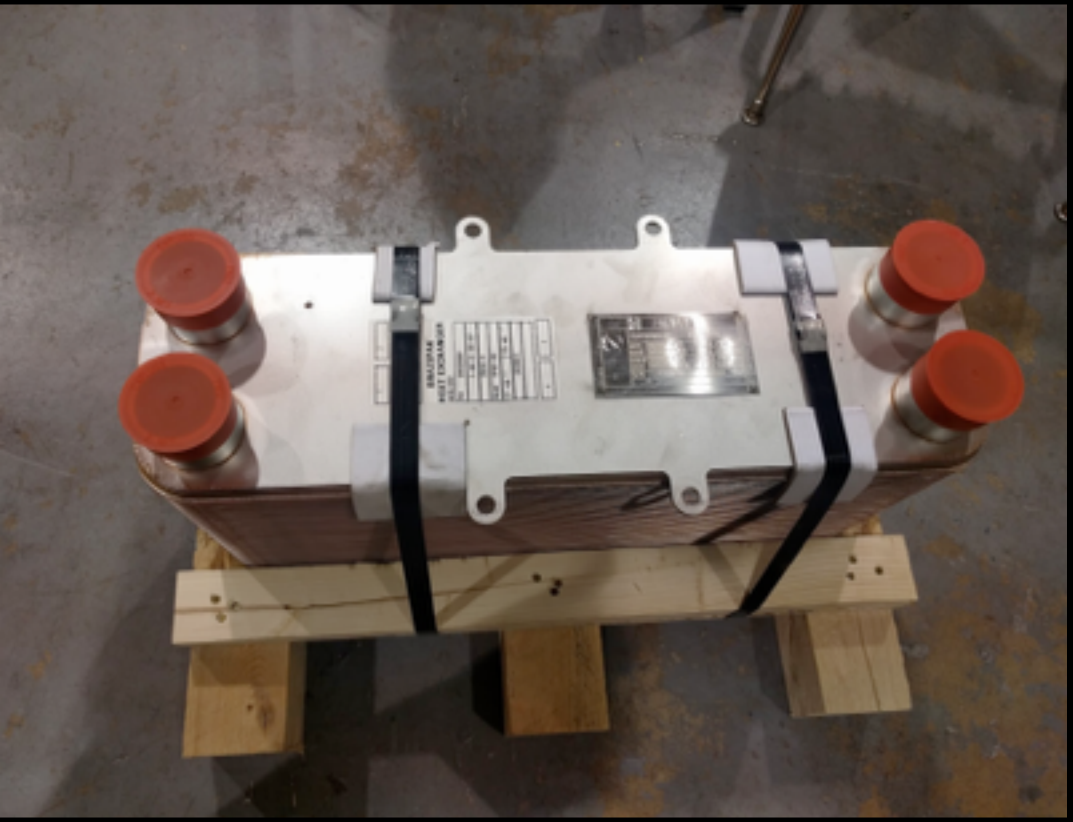


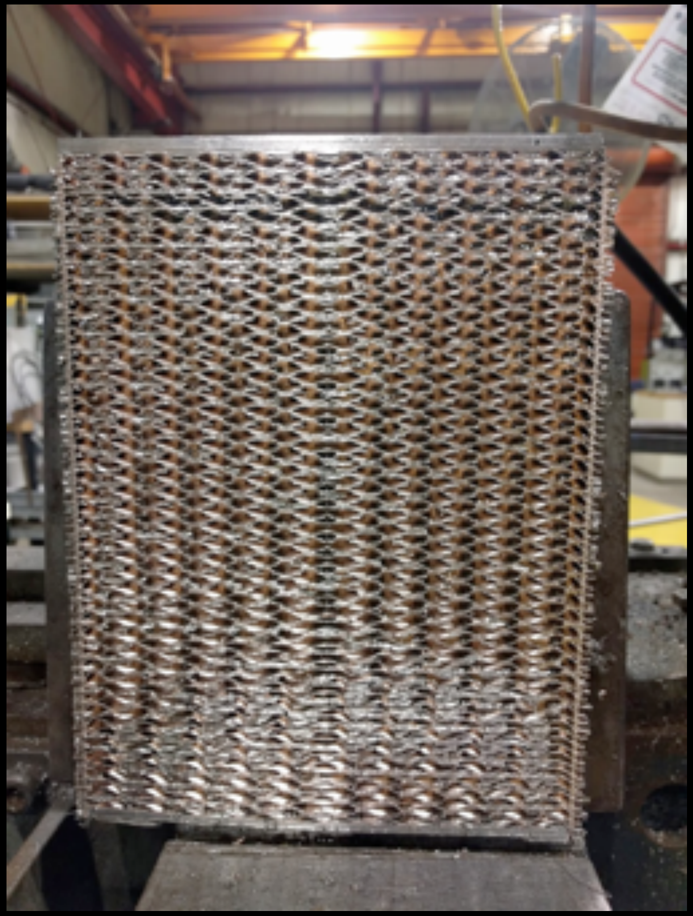


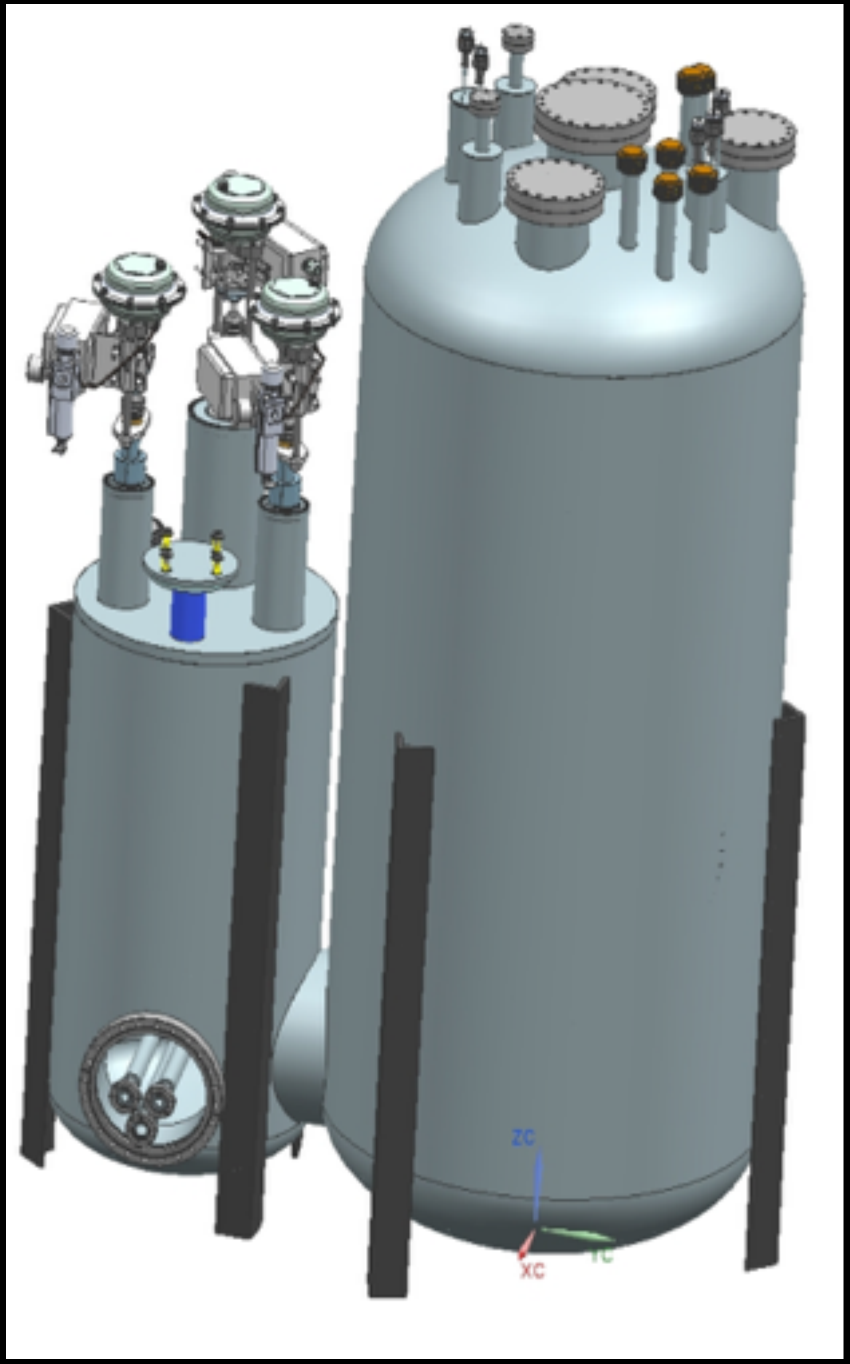
Success!

LXe Tower

- To achieve electronegative impurity (<0.4 ppb of O2 equivalent), recirculate at 500 slpm through a getter
- 11 kW to condense at that rate
  - 1 kW of power available underground
- Efficient heat exchanger in the LXe Tower
  - FNAL deliverable

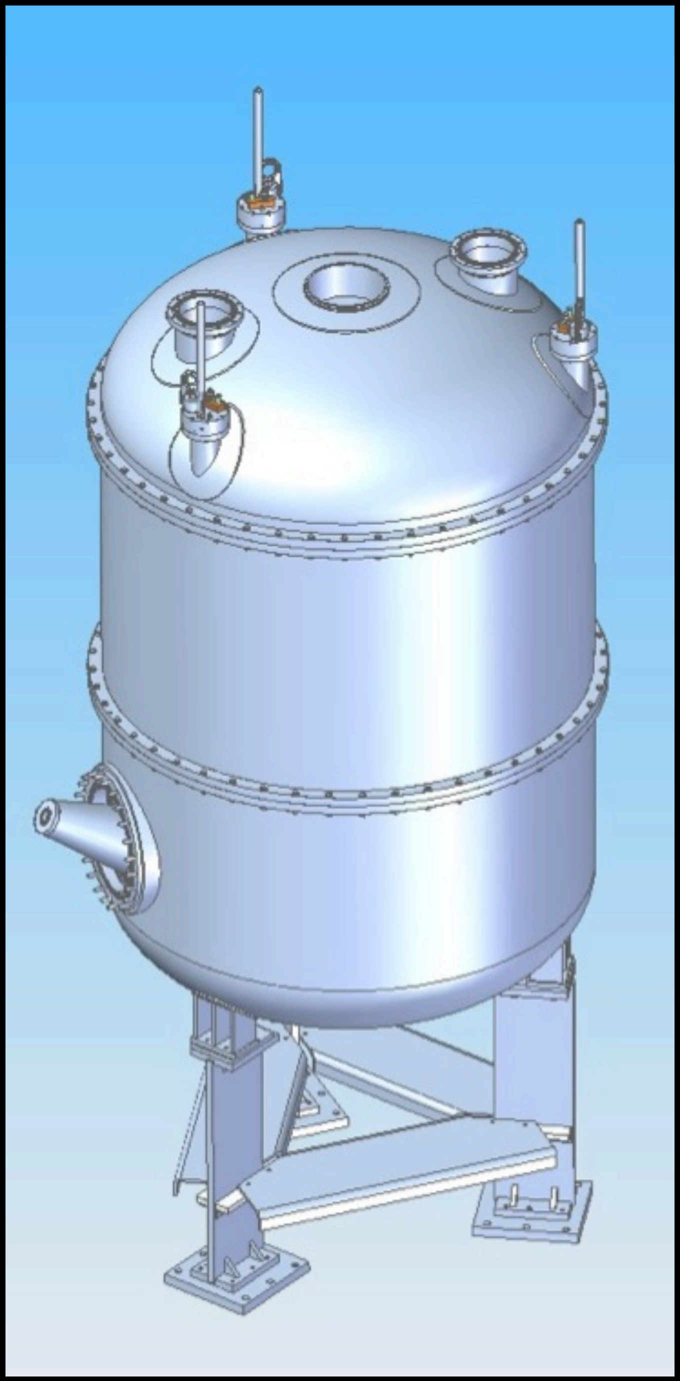






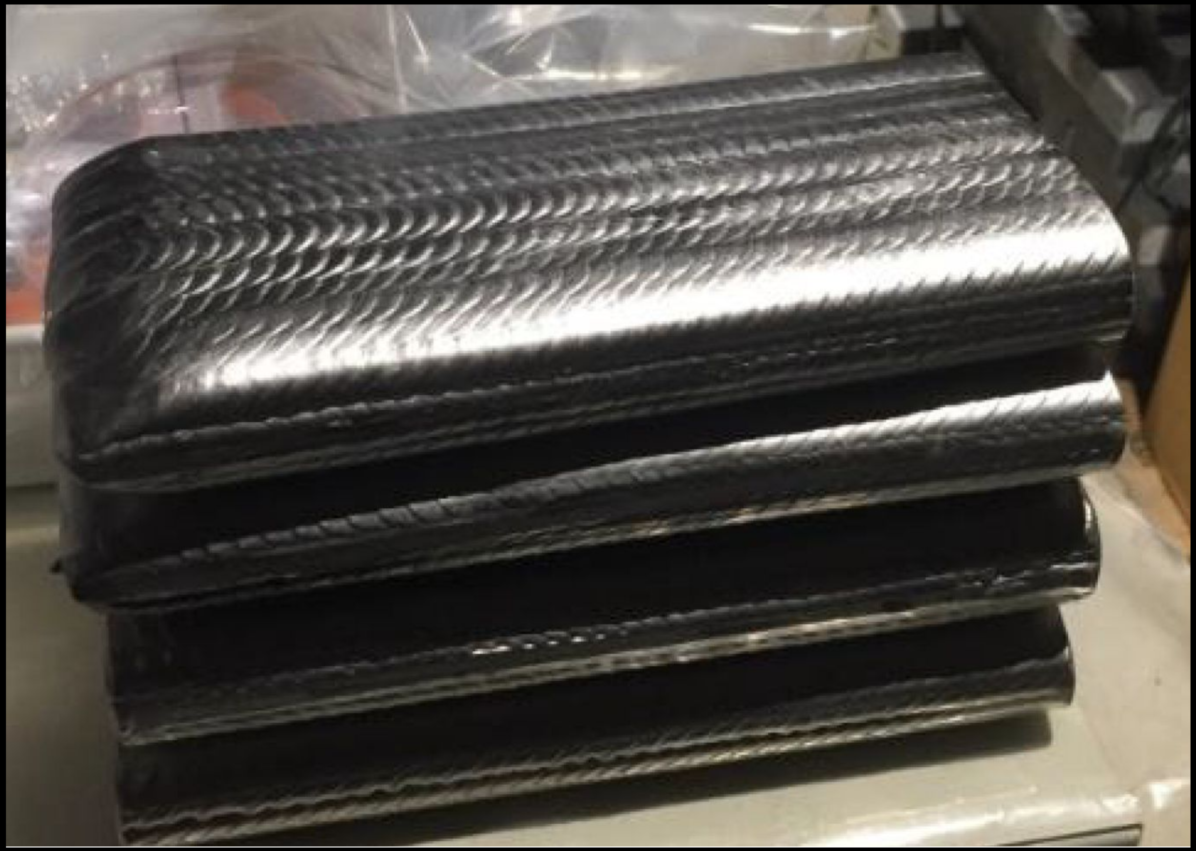
Background suppression by screening

- Every component is screened and simulated for radioactivity
  - E.g. cryostat made of the most radiopure titanium in the world: sub pub levels of U,Th, < 0.05 counts in 1000 days after cuts
  - Similar campaign working with Hamamatsu on PMTs
- Backed up by QA during production



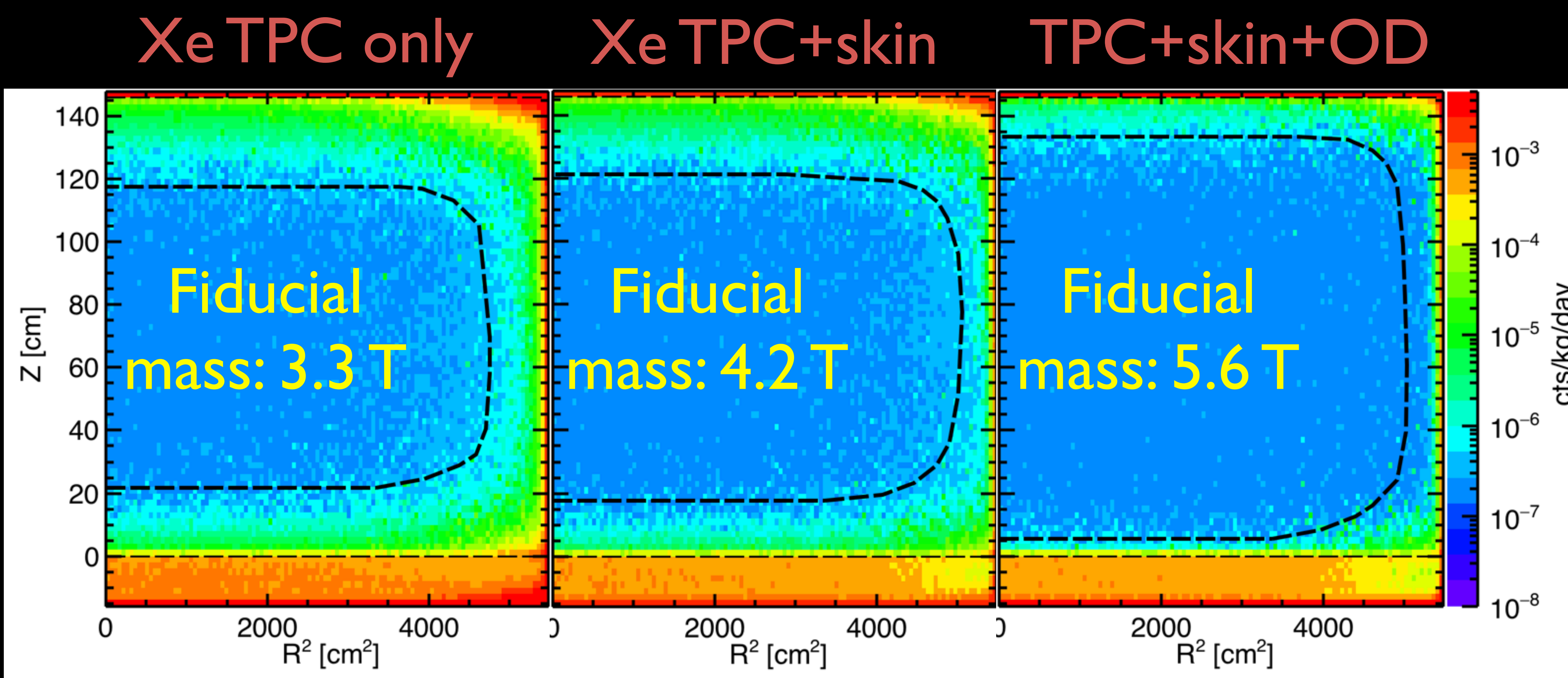
Background suppression by screening

- Weld samples of Ti screened in March - 100x hotter than raw materials
- Fabrication halted, massive screening campaign started
- Manufacturer used the wrong weld tip - the color code on one provided by supplier was missing
- Caught in time



Background suppression by veto

- Two component outer detector
  - Gd-loaded liquid scintillator
  - instrumented skin

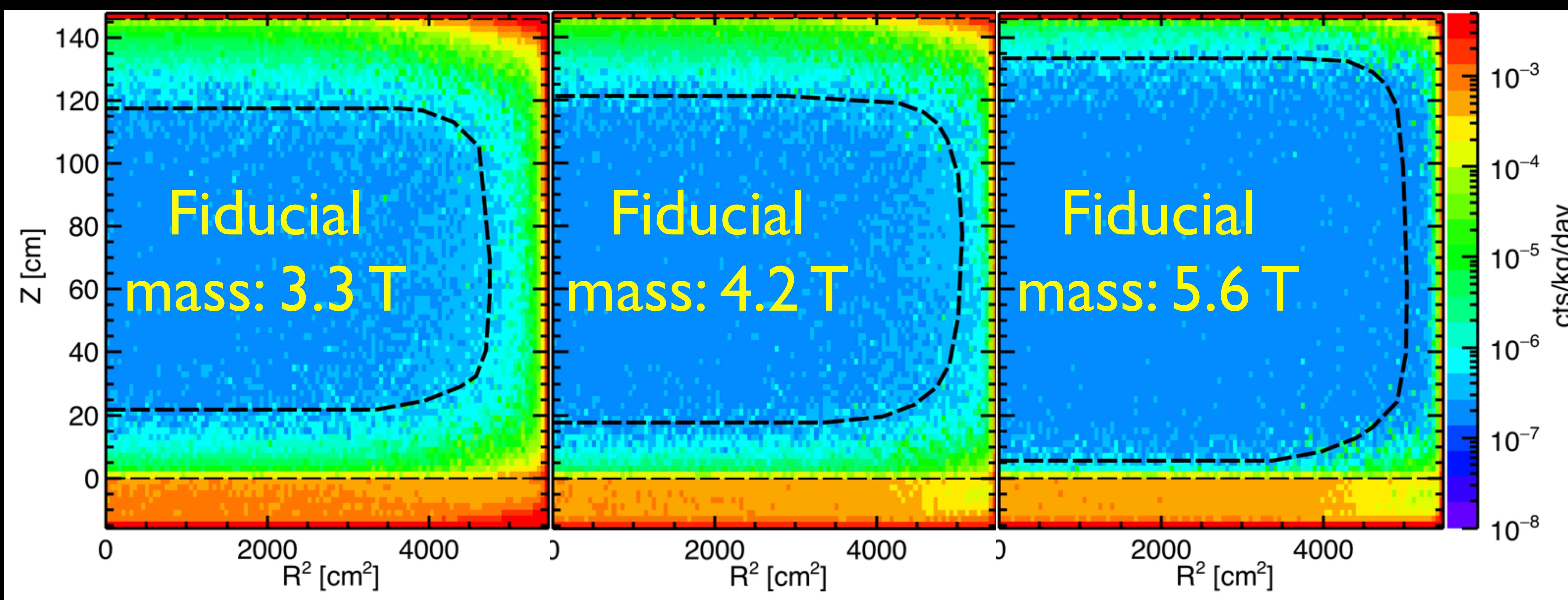


Background suppression by veto

- Two component outer detector
  - G
  - in

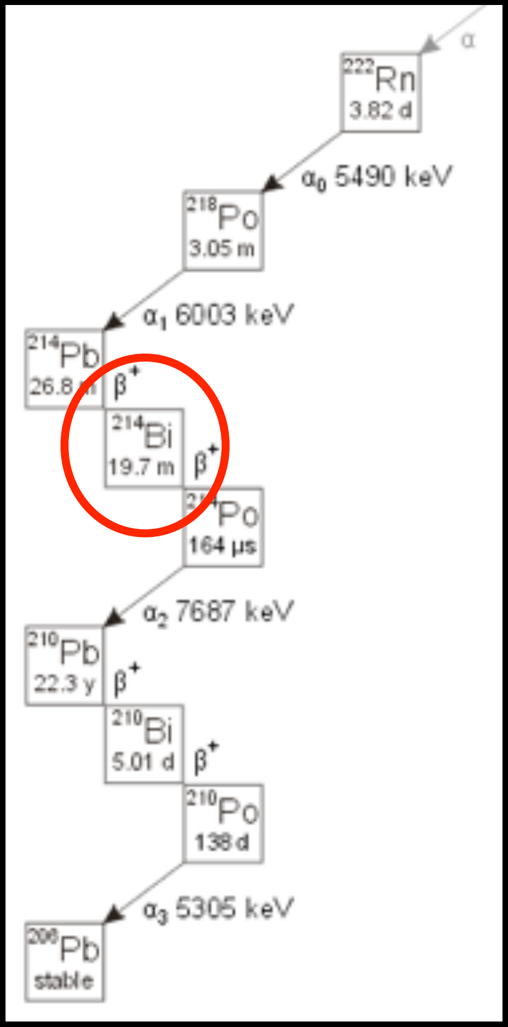
With veto, detector components are a subdominant background!

Xe TPC only Xe TPC+skin TPC+skin+OD



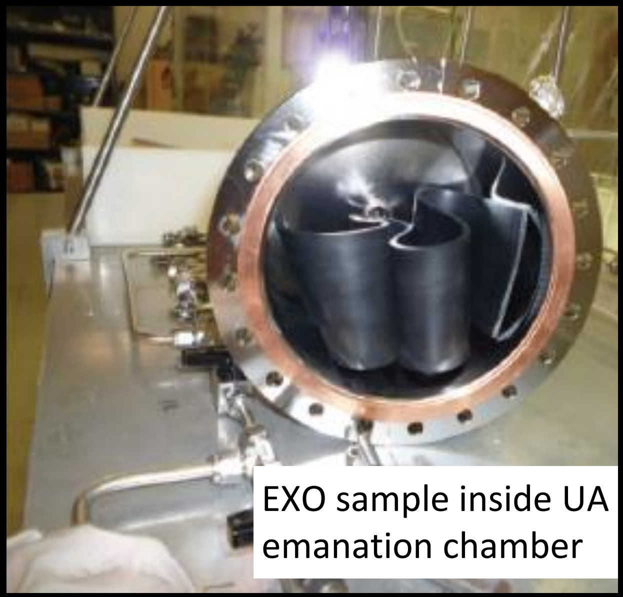
Internal backgrounds

- Radon, Krypton, Argon
- Distributed throughout the liquid volume
- ER backgrounds (can discriminate, thankfully)
- Radon requirement (goal) of 20(1) mBq



Radon emanation measurements

Dust is a killer!



EXO sample inside UA emanation chamber

Internal backgrounds

- Contributes half our radon budget
- Emanation measurements of "clean room dust"
- Requirement of <500 ng/cm^2 of dust in LZ
  - Goal of 5 ng/cm^2
  - SNO achieved 20 ng/cm^2, BOREXINO 1 ng/cm^2
  - 1 gram total!
- Cleanliness protocols, witness plate protocols, packaging protocols

Dust is a killer!

Intrinsic Contamination Backgrounds	Mass (kg)	Composite	U early (mBq/kg)	U late (mBq/kg)	Th early (mBq/kg)	Th late (mBq/kg)	Co60 (mBq/kg)	K40 (mBq/kg)	n/yr (inc. S.F. rej.)	ER (cts)	NR (cts) (w/ SF rej.)
Upper PMT Structure	40.5	Y	3.90	0.23	0.49	0.38	0.00	1.46	2.53	0.05	0.000
Lower PMT Structure	69.9	Y	2.40	0.13	0.30	0.24	0.00	0.91	6.06	0.05	0.001
R11410 3" PMTs	91.9	Y	71.63	3.20	3.12	2.99	2.82	15.41	81.83	1.46	0.013
R11410 PMT Bases *	2.8	Y	287.74	75.80	28.36	27.93	1.43	69.39	34.65	0.36	0.004
R8778 2" PMTs	6.1	Y	137.50	59.38	16.88	16.88	16.25	412.50	52.80	0.13	0.008
R8520 Skin 1" PMTs	2.2	Y	60.50	5.19	4.75	4.75	24.20	332.76	4.60	0.02	0.001
R8520 Skin PMT Bases *	0.2	Y	212.95	108.46	42.19	37.62	2.23	123.61	3.62	0.00	0.000
PMT Cabling	103.5	Y	29.83	1.47	3.31	3.15	0.65	33.14	2.65	1.43	0.000
TPC PTFE	184.0	N	0.02	0.02	0.03	0.03	0.00	0.12	22.54	0.06	0.008
Grid Wires	0.75	N	1.20	0.27	0.33	0.49	1.60	0.40	0.02	0.00	0.000
Grid Holders	62.2	Y	1.20	0.27	0.33	0.49	1.60	0.40	6.33	0.27	0.002
Field Shaping Rings	91.6	Y	5.41	0.09	0.28	0.23	0.00	0.54	10.83	0.23	0.004
TPC Sensors	0.90	Y	21.09	13.51	22.89	14.15	0.50	26.29	24.77	0.01	0.002
TPC Thermometers	0.06	Y	335.50	90.46	38.48	25.02	7.26	3,359	1.49	0.05	0.000
Xe Recirculation Tubing	15.1	Y	0.79	0.18	0.23	0.33	1.05	0.30	0.64	0.00	0.000
HV Conduits and Cables	137.7	Y	1.9	2.0	0.5	0.6	1.4	1.2	4.9	0.04	0.001
HX and PMT Conduits	199.6	Y	1.25	0.40	2.59	0.66	1.24	1.47	5.33	0.06	0.001
Cryostat Vessel	2406.1	N	1.59	0.11	0.29	0.25	0.07	0.56	123.70	0.63	0.013
Cryostat Seals	33.7	Y	73.91	26.22	3.22	4.24	10.03	69.12	38.78	0.45	0.002
Cryostat Insulation	23.8	Y	18.91	18.91	3.45	3.45	1.97	51.65	69.83	0.43	0.007
Cryostat Teflon Liner	26.0	N	0.02	0.02	0.03	0.03	0.00	0.12	3.18	0.00	0.000
Outer Detector Tanks	3199.3	Y	0.16	0.39	0.02	0.06	0.04	5.36	77.96	0.45	0.001
Liquid Scintillator	17640.3	Y	0.01	0.01	0.01	0.01	0.00	0.00	14.28	0.03	0.000
Outer Detector PMTs	204.7	Y	570	470	395	388	0.00	534	7,587	0.01	0.000
Outer Detector PMT Supports	770.0	N	1.20	0.27	0.33	0.49	1.60	0.40	14.30	0.00	0.000
Subtotal (Detector Components)										**6.20**	**0.070**
222Rn (2.0 μBq/kg)										722	-
220Rn (0.1 μBq/kg)										122	-
natKr (0.015 ppt g/g)										24.5	-
natAr (0.45 ppb g/g)										2.47	-
210Bi (0.1 μBq/kg)										40.0	-
Laboratory and Cosmogenics										4.3	0.06
Fixed Surface Contamination										0.19	0.37
Subtotal (Non-ν counts)										**921**	**0.50**
Physics Backgrounds											
136Xe 2νββ										67	0
Astrophysical ν counts (pp+7Be+13N)										255	0
Astrophysical ν counts (8B)										0	0**
Astrophysical ν counts (Hep)										0	0.21
Astrophysical ν counts (diffuse supernova)										0	0.05
Astrophysical ν counts (atmospheric)										0	0.46
Subtotal (Physics backgrounds)										322	0.72
Total										1,240	1.22
Total (with 99.5% ER discrimination, 50% NR efficiency)										6.22	0.61

My summary of the summary table → 6 ER, 0.6 NR in 1000 days!

Backgrounds summary

Subtotal (Non-v counts)	**921**	**0.50**
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Total (with 99.5% ER discrimination, 50% NR efficiency)	6.22	0.61

- Lots of neutrinos - significant fraction of both ER and NR counts
- Discrimination cuts are important

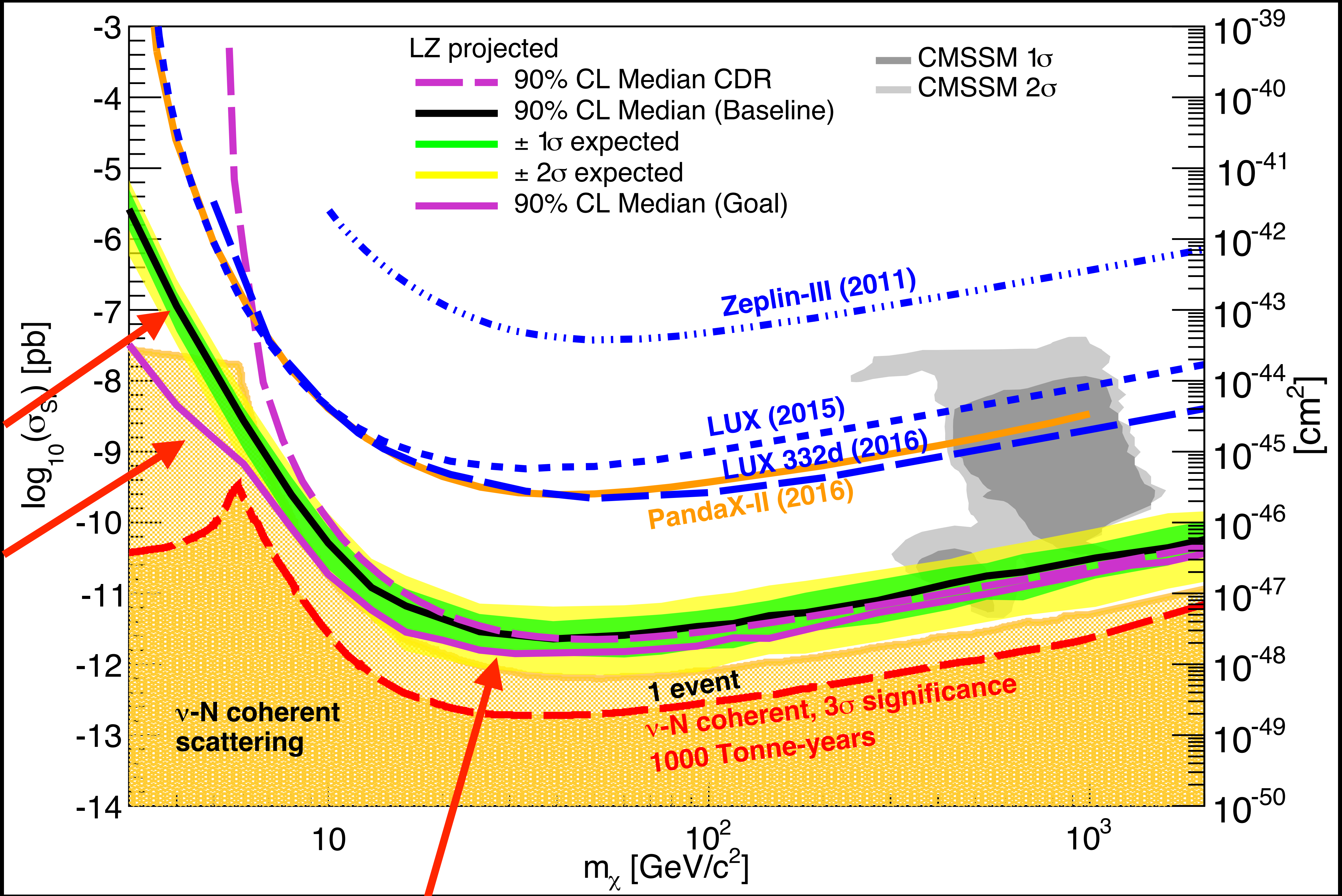
My summary of the summary table → 6 ER, 0.6 NR in 1000 days!

Sensitivity projections

Detector Parameter	Reduced	Baseline	Goal
Light collection (PDE)	0.05	0.075	0.12
Drift field (V/cm)	160	310	650
Electron lifetime (μs)	850	850	2800
PMT phe detection	0.8	0.9	1.0
N-fold trigger coincidence	4	3	2
^{222}Rn (mBq in active region)	13.4	13.4	0.67
Live days	1000	1000	1000

- ~6 keVnr threshold in baseline scenario (LUX achieved 4.5 keVnr)
  - Driven by S1 trigger coincidence threshold
- Better than 99.5% ER/NR discrimination at this field

Sensitivity projections (1000 days)

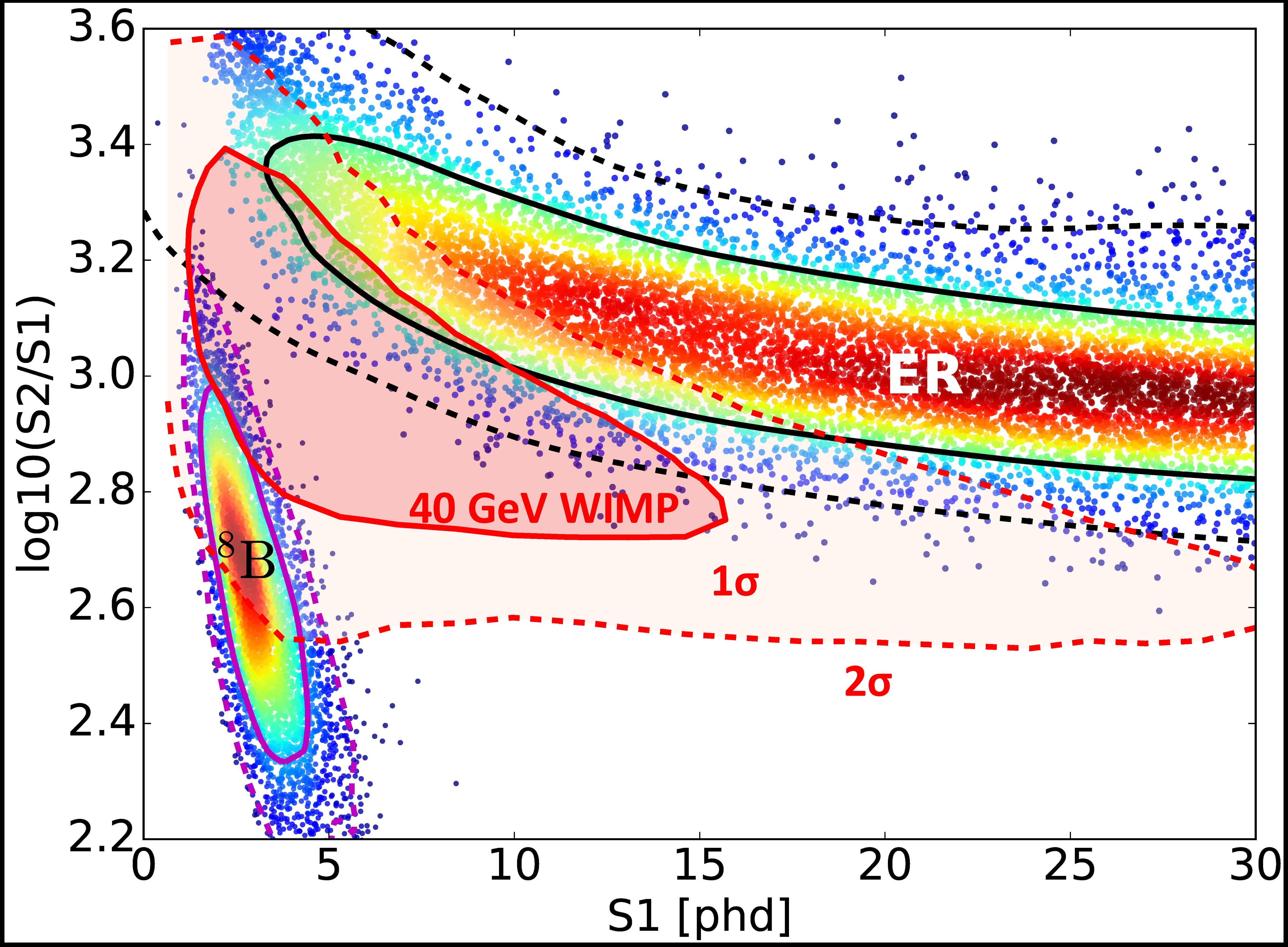


~7 8B events

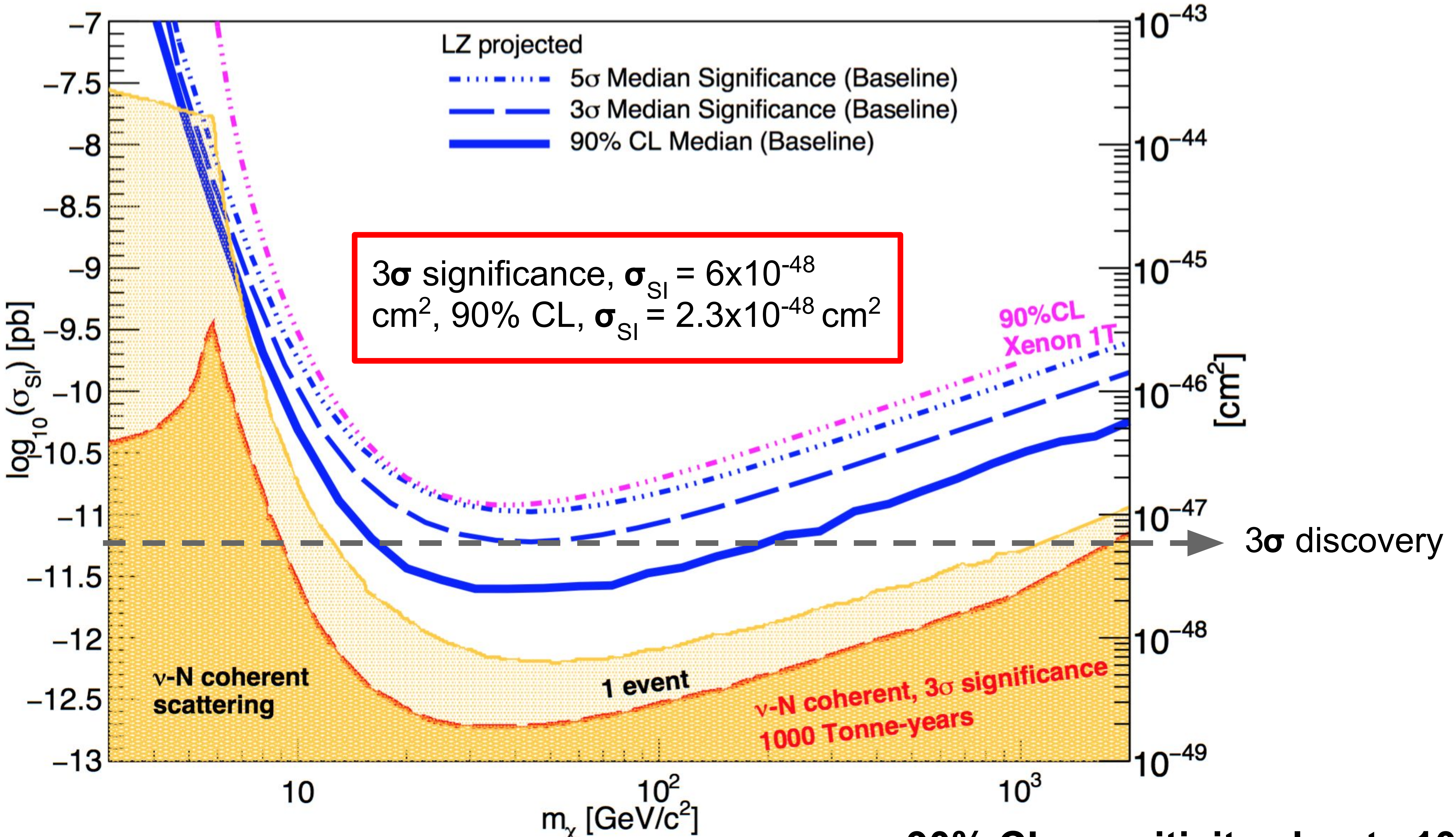
~700 8B events

@40 GeV: 2.3e-48 Nominal
1.1e-48 Goal

WIMP signal region



Sensitivity projections (1000 days)



90% CL sensitivity about x10 better than XENON1T

Schedule

- Competition is fierce!
  - XENON1T already buying up PMTs and xenon to go to XENONnT
    - Infrastructure in place - update of TPC and cryostat
    - XENON1T done in November, 2018, XENONnT physics start in July, 2019, as of talk in August
- PandaX back in the race as well
- We want to get there first
- Did I mention LZ was a DOE project?

Schedule

- CD1 in April, 2015
  - a million internal reviews (Preliminary)
- CD2 in August, 2016
  - a million internal reviews (Final)
- CD3 in February, 2017
  - We can start construction!
    (after a bunch of internal reviews)

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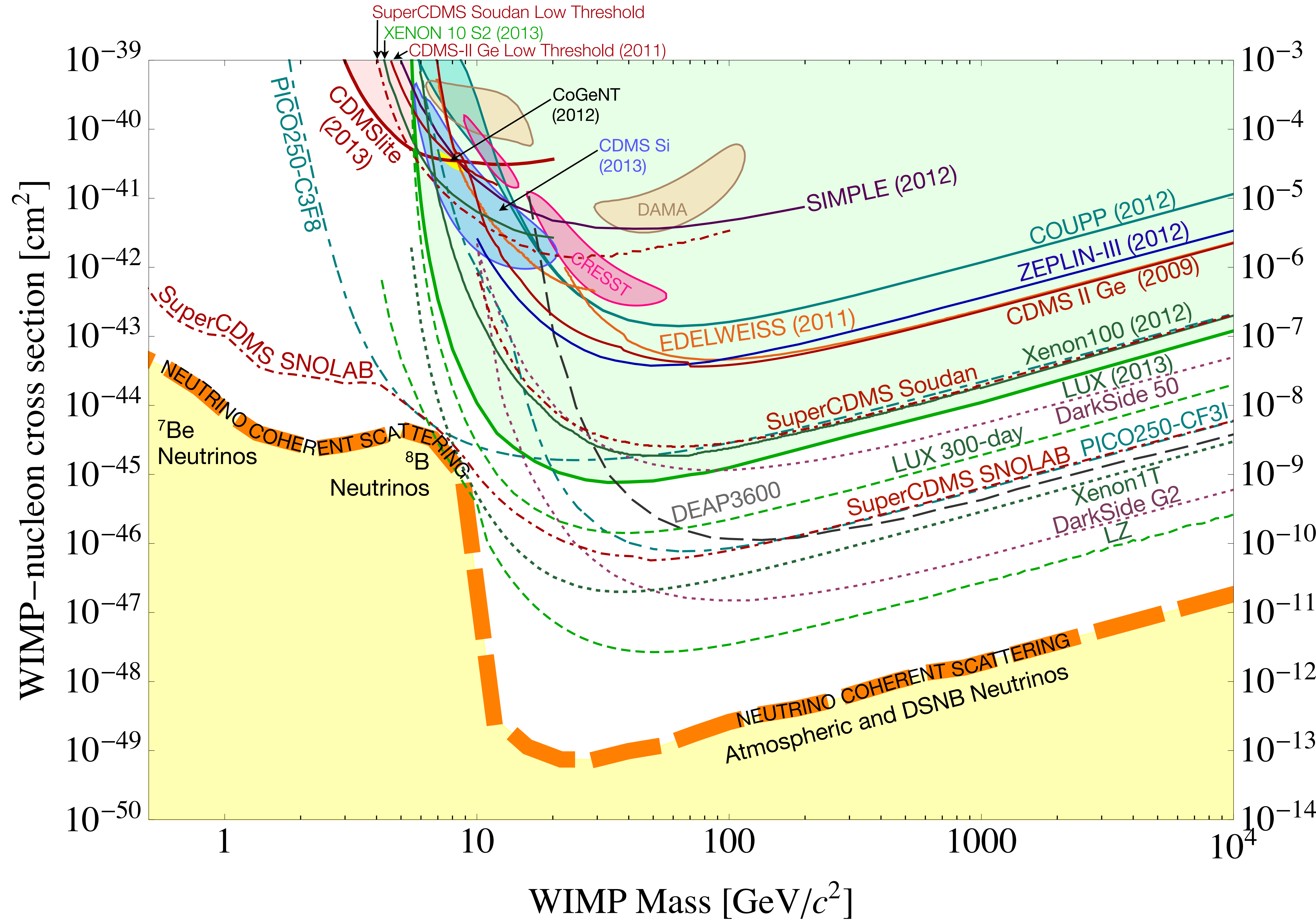
    (after a bunch of internal reviews)

  - Also some more DOE reviews (status reviews?)

- Current plan has us taking real data in early 2020
  - Trying hard to advance that

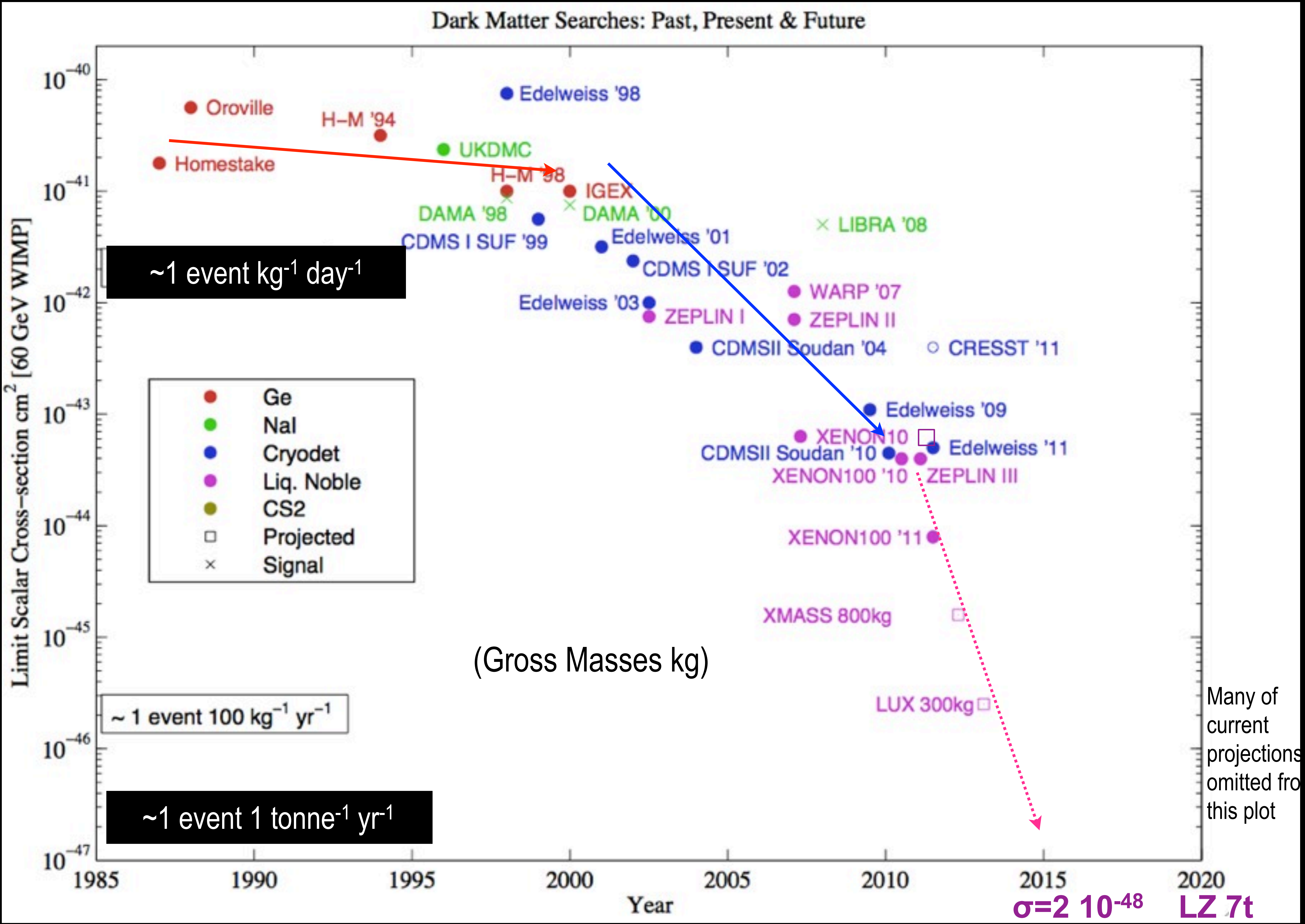
Summary

- Dark matter is one of the most interesting topics in particle physics
  - Rapid progress in last two decades
- Liquid xenon TPCs are a good technology in the search (although not the only one)
  - Understanding of LXe is much better than it was 10 years ago
- LZ is poised to achieve a factor x40 more sensitivity than current best limits
- Competition is fierce so we're moving as fast as we can!

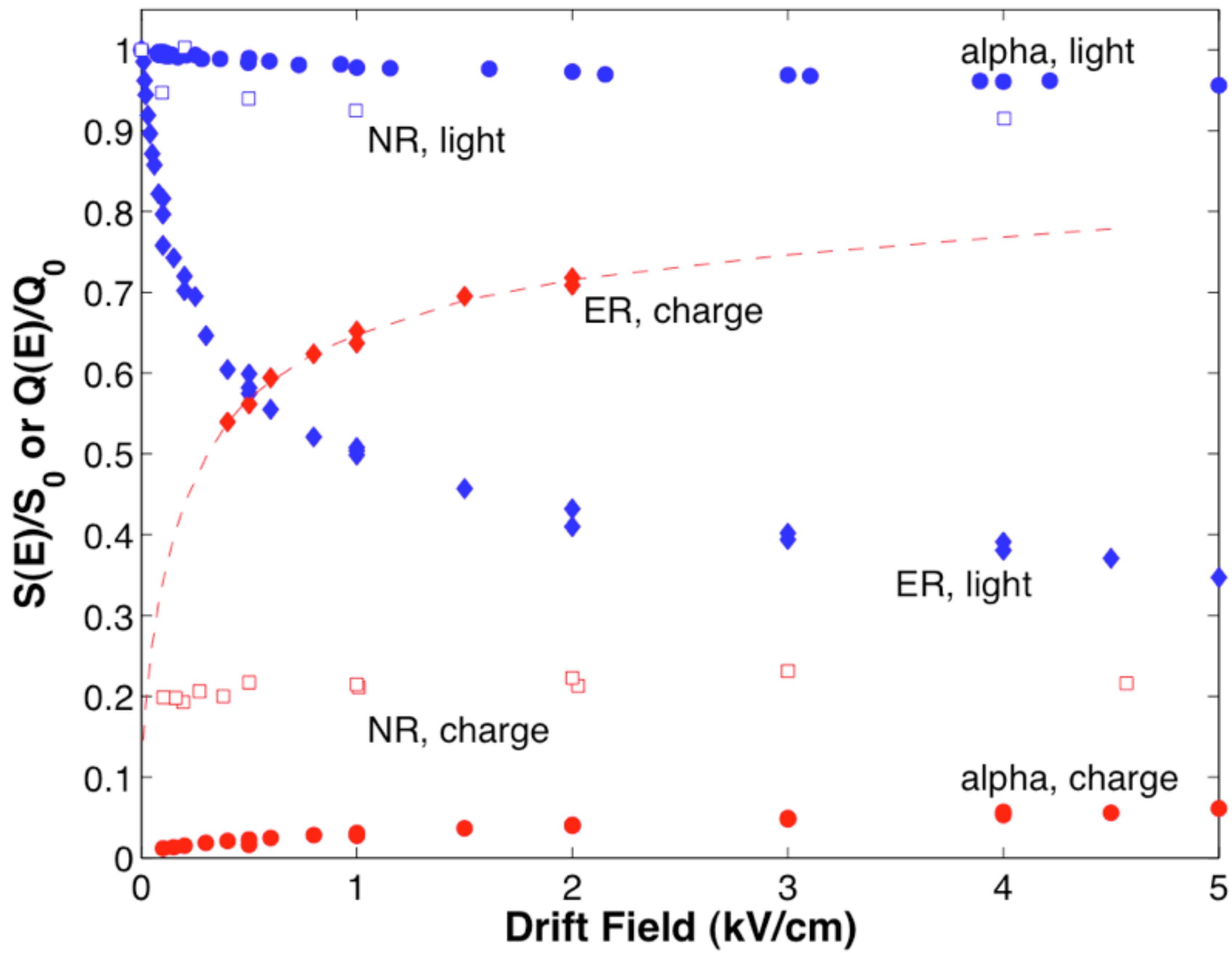


SuperCDMS Soudan Low Threshold
XENON 10 S2 (2013)
CDMS-II Ge Low Threshold (2011)
CoGeNT (2012)
CDMS Si (2013)
CDMSlite (2013)
PICO250-C3F8
DAMA
SIMPLE (2012)
COUPP (2012)
ZEPLIN-III (2012)
CDMS II Ge (2009)
CRESST
EDELWEISS (2011)
Xenon100 (2012)
SuperCDMS Soudan
LUX (2013)
DarkSide 50
LUX 300-day
PICO250-CF3I
SuperCDMS SNOLAB
DEAP3600
Xenon1T
DarkSide G2
LZ
SuperCDMS SNOLAB
NEUTRINO COHERENT SCATTERING
7Be Neutrinos
8B Neutrinos
NEUTRINO COHERENT SCATTERING
Atmospheric and DSNB Neutrinos
WIMP–nucleon cross section [cm2]
WIMP Mass [GeV/c2]

End

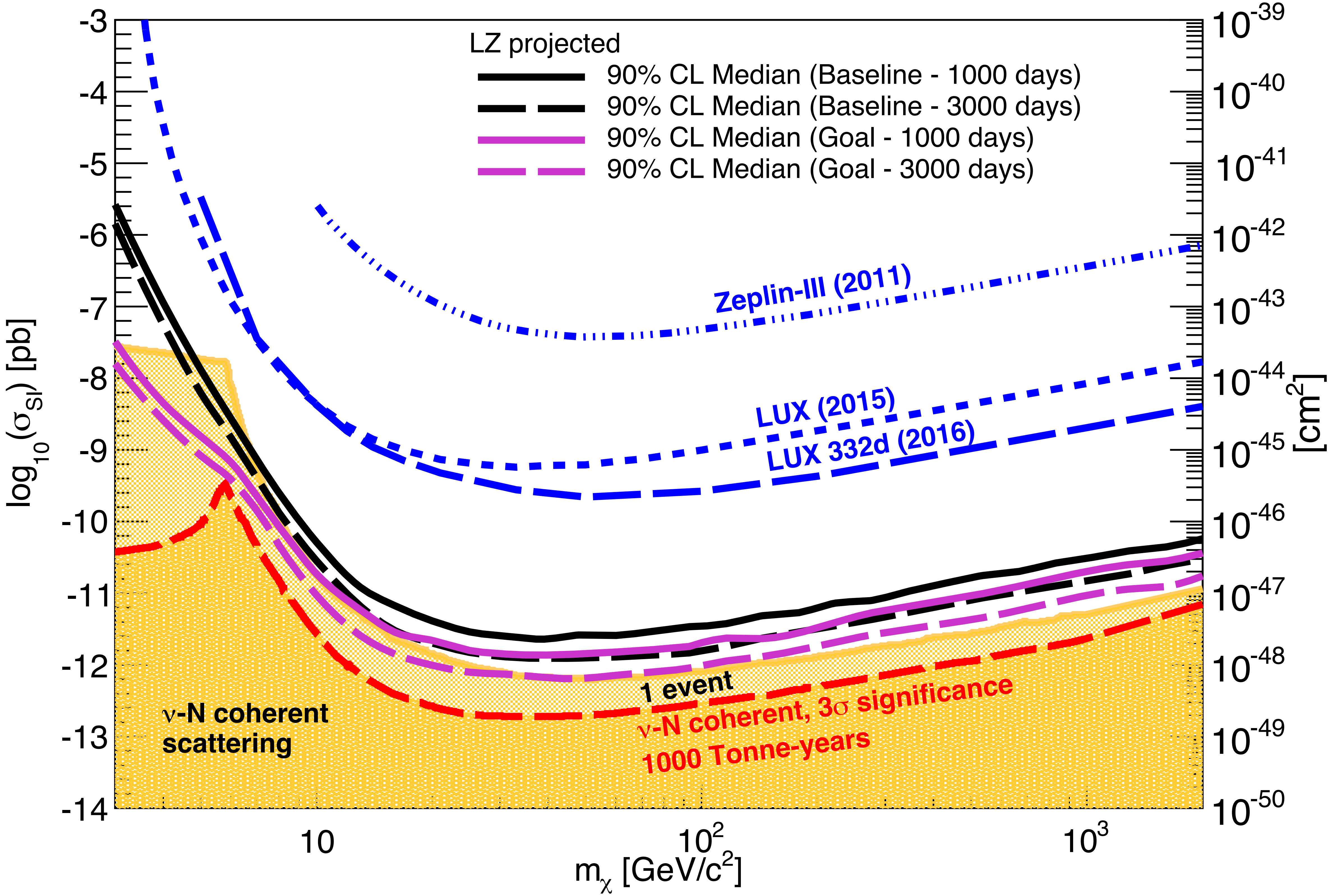

Dark Matter Searches: Past, Present & Future
Oroville
H–M '94
Homestake
Edelweiss '98
UKDMC
H–M '98
IGEX
DAMA '98
DAMA '00
CDMS I SUF '99
Edelweiss '01
CDMS I SUF '02
LIBRA '08
WARP '07
Edelweiss '03
ZEPLIN I
ZEPLIN II
CDMSII Soudan '04
CRESST '11
Edelweiss '09
XENON10
Edelweiss '11
CDMSII Soudan '10
XENON100 '10
ZEPLIN III
XENON100 '11
XMASS 800kg
LUX 300kg
Ge
NaI
Cryodet
Liq. Noble
CS2
Projected
Signal
~1 event kg^{-1} day^{-1}
~ 1 event 100 kg^{-1} yr^{-1}
~1 event 1 tonne^{-1} yr^{-1}
(Gross Masses kg)
Limit Scalar Cross–section cm^2 [60 GeV WIMP]
Year
Many of current projections omitted fro this plot
σ=2 10^{-48}
LZ 7t

Some LXe physics

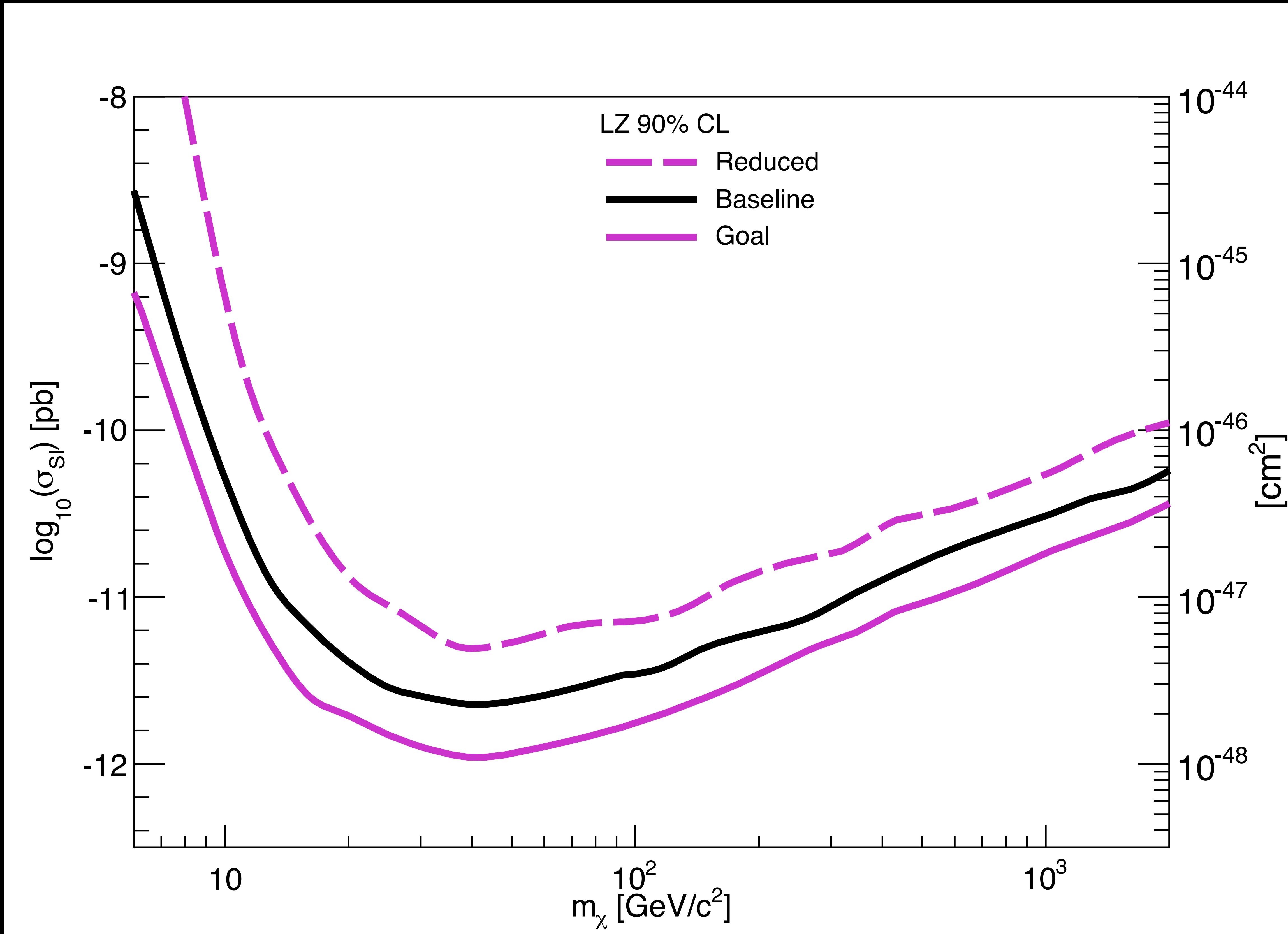


E. Aprile et al., Phys. Rev. Lett. **97**, 081302 (2006)

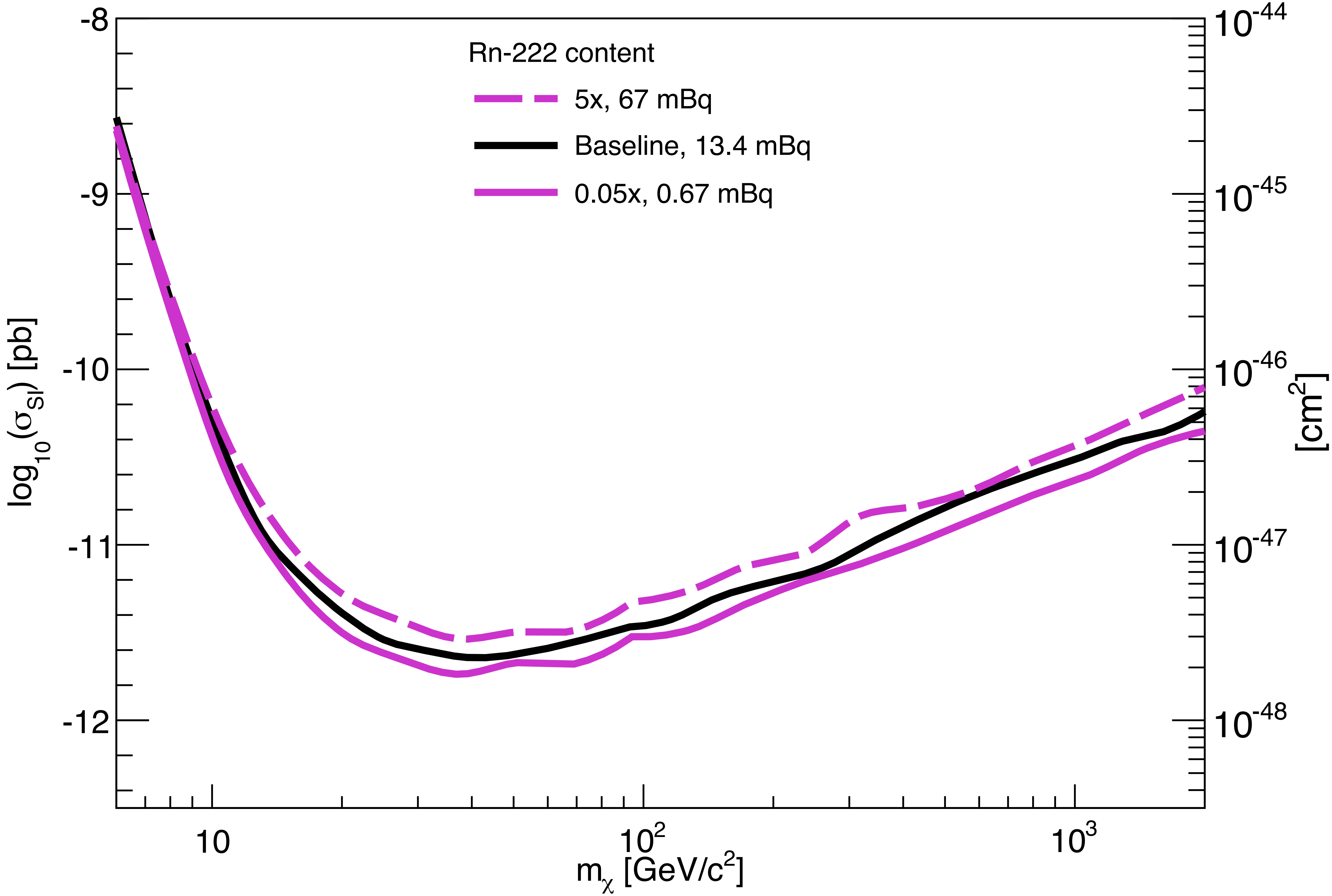
For 122 keV ER, 56 keV NR



LZ projected
90% CL Median (Baseline - 1000 days)
90% CL Median (Baseline - 3000 days)
90% CL Median (Goal - 1000 days)
90% CL Median (Goal - 3000 days)
Zeplin-III (2011)
LUX (2015)
LUX 332d (2016)
1 event
ν-N coherent scattering
ν-N coherent, 3σ significance
1000 Tonne-years
$\log_{10}(\sigma_{SI})$ [pb]
[cm^2]
m_χ [GeV/c^2]



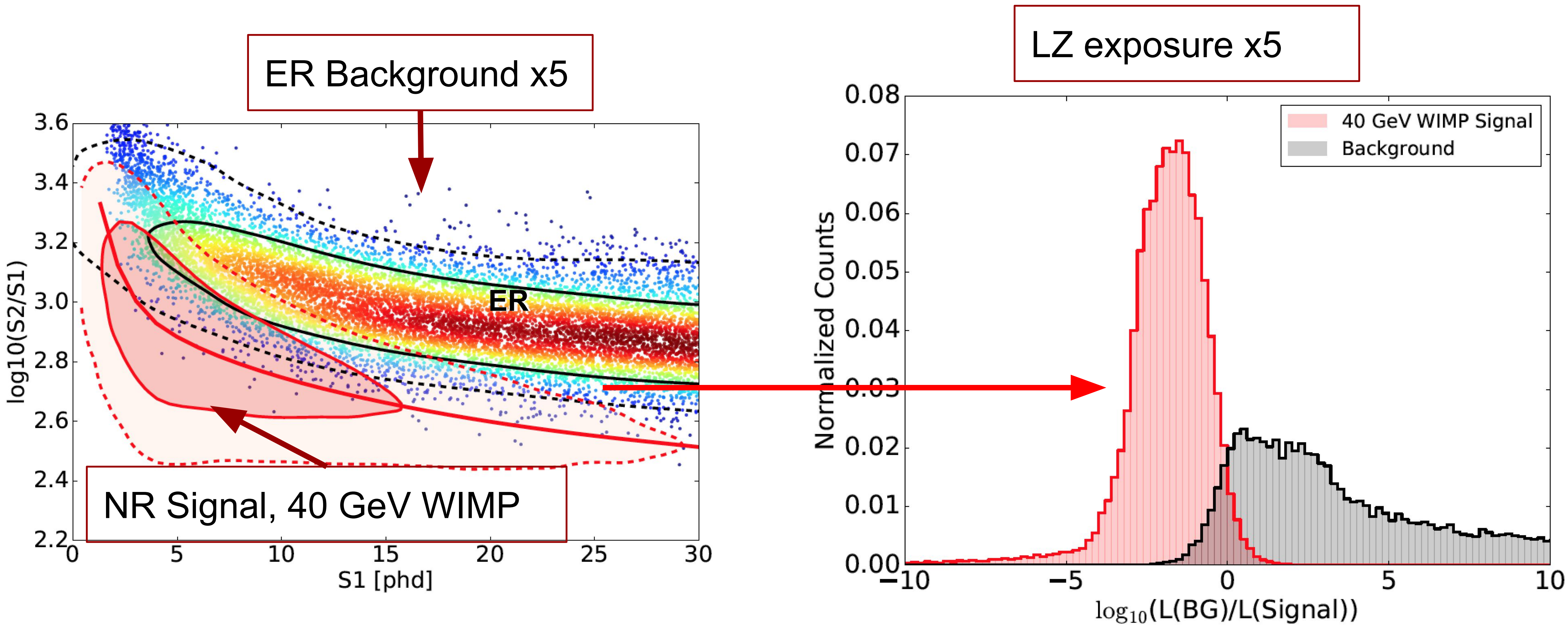
LZ 90% CL
Reduced
Baseline
Goal
-8
-9
-10
-11
-12
$\log_{10}(\sigma_{SI})$ [pb]
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
[cm^2]
10
10^2
10^3
m_χ [GeV/c^2]



Rn-222 content
5x, 67 mBq
Baseline, 13.4 mBq
0.05x, 0.67 mBq
-8
-9
-10
-11
-12
$\log_{10}(\sigma_{SI})$ [pb]
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
[cm^2]
10
10^2
10^3
m_χ [GeV/c^2]

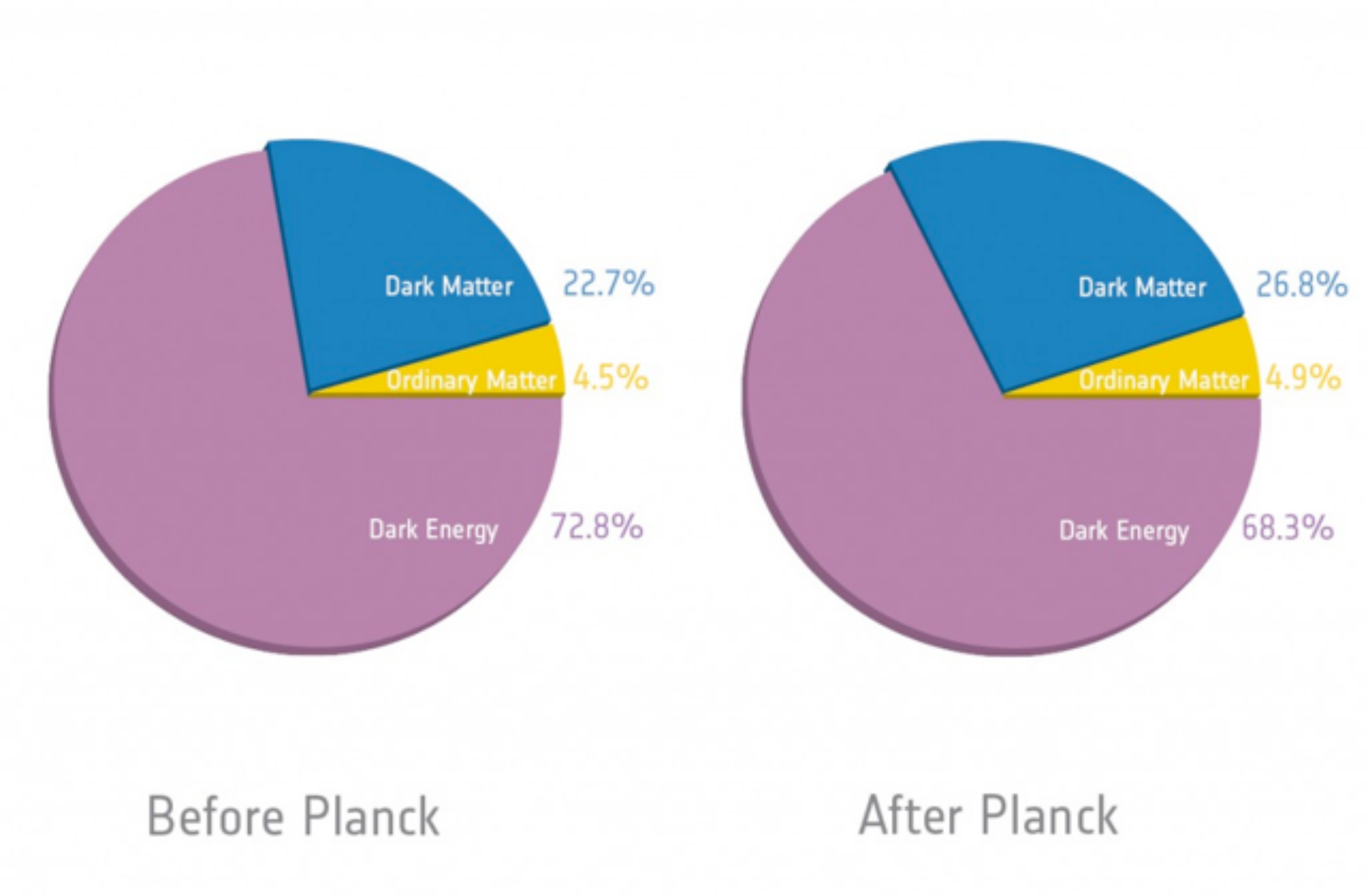
PLR (Profile Likelihood Ratio)

- Simple fiducial of 5600 kg (X,Y,Z position info not yet implemented in PLR)
- Dominant ER: Rn, Kr, pp-neutrinos spatially uniform like signal



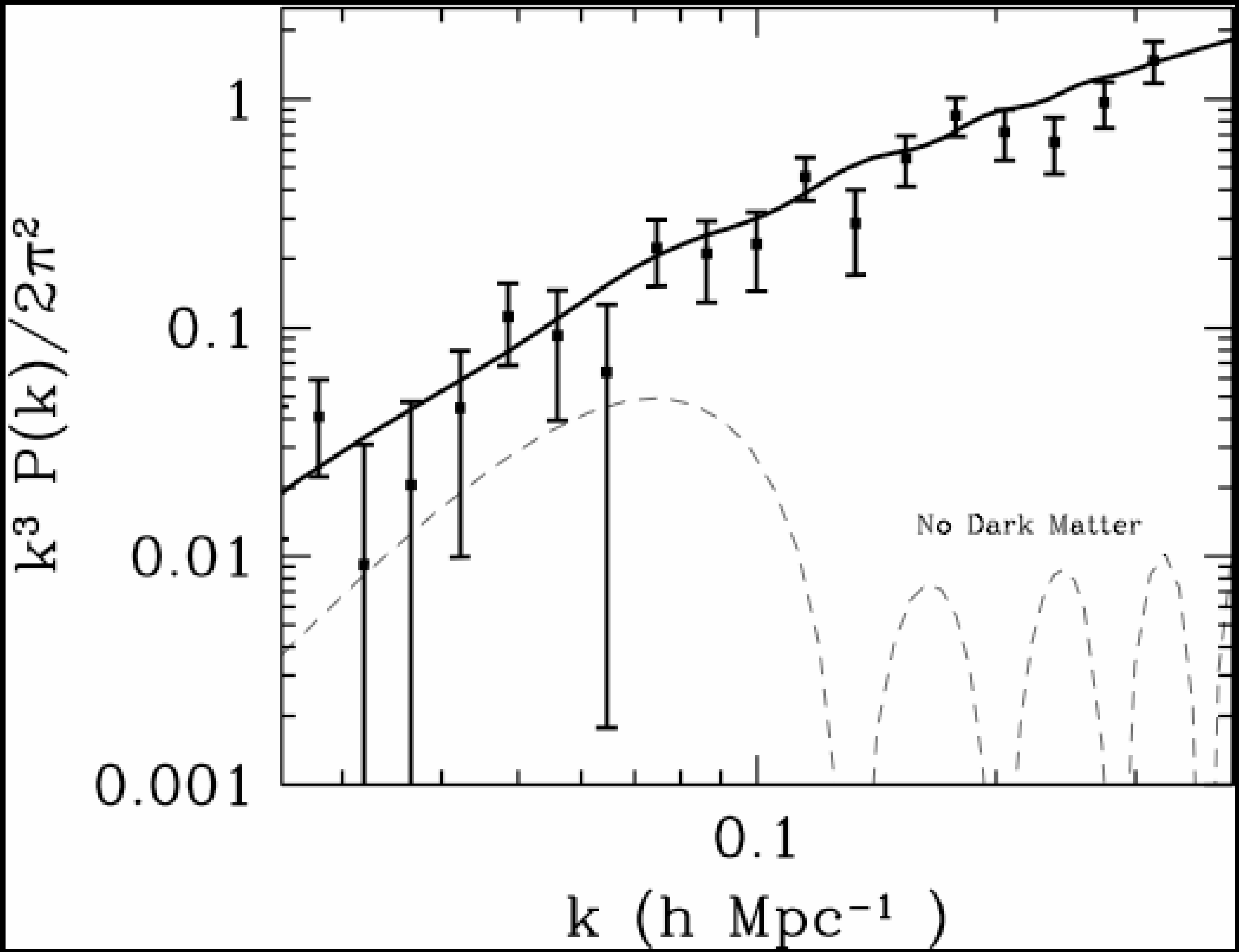
There is pretty strong consensus regarding how much stuff there is in the universe

By that same consensus, we only understand 5% of it



Dark matter - evidence?

- Galaxy rotation curves
- Galaxy clusters
- Gravitational lensing
- Large Scale Structure →
- Cosmic microwave background



So what is it?

- We know it interacts gravitationally
- It is “dark” - should not interact with light or electromagnetism
- Nearly collisionless
- Slow

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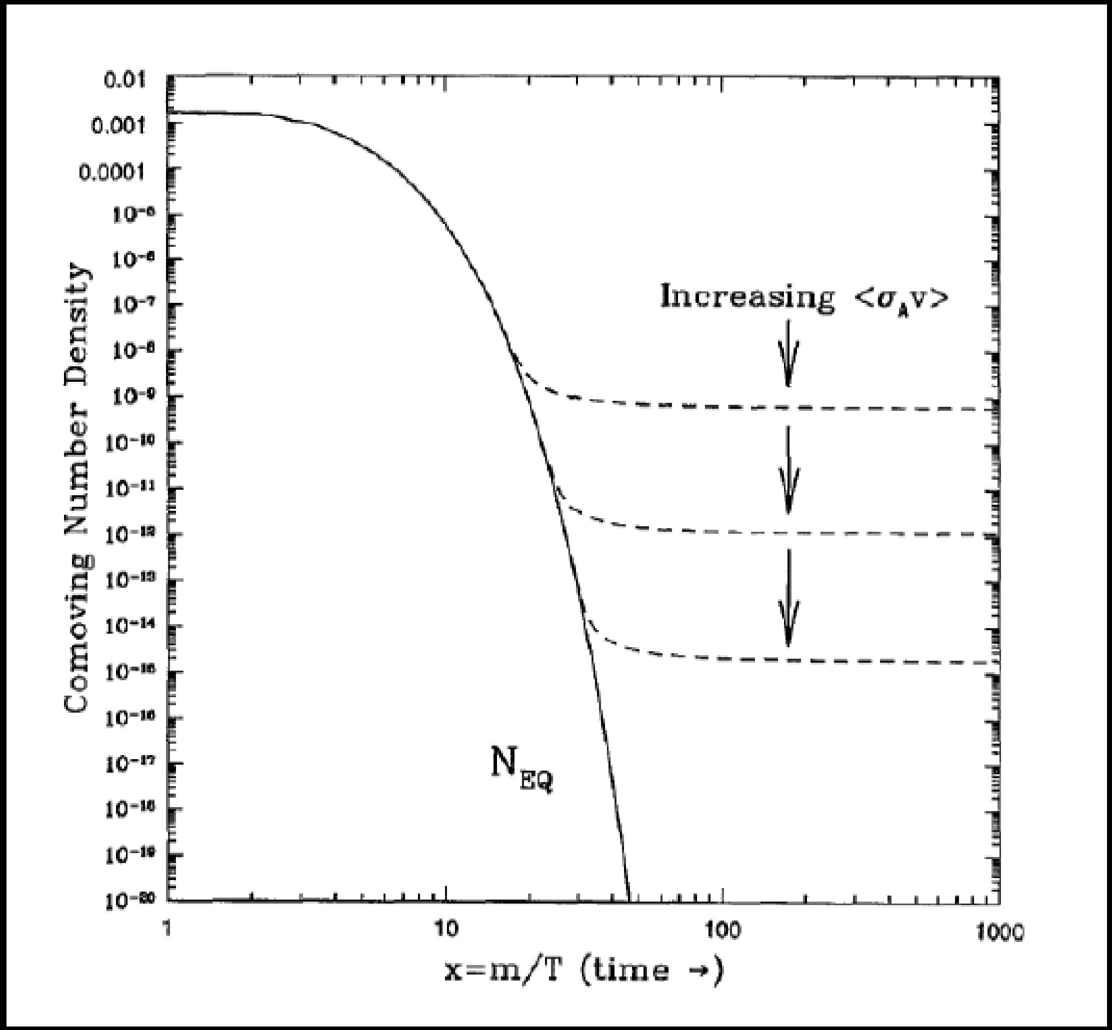
Beyond the Standard Model!

WIMPs

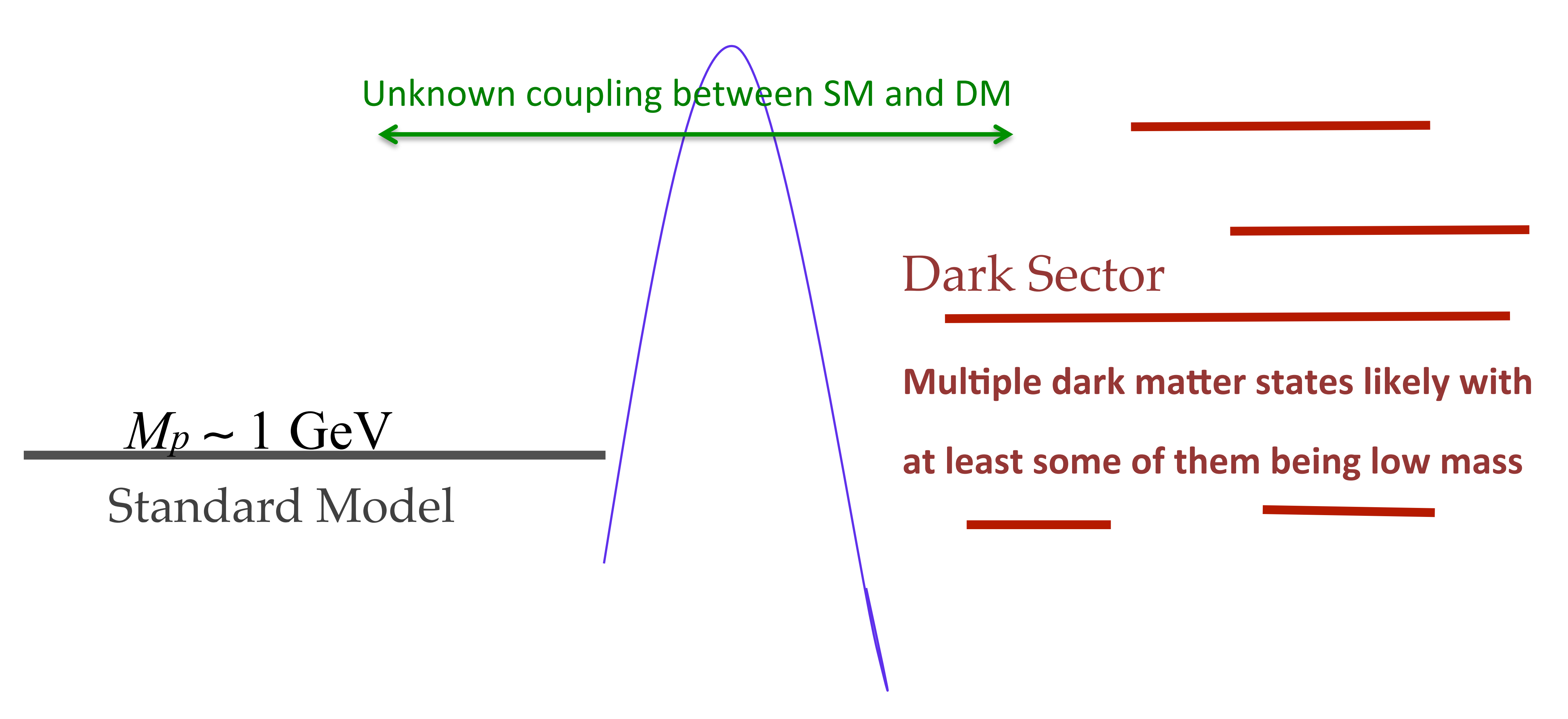
- Most discussed candidate is Weakly Interacting Massive Particle
  - Produced during big bang
  - Decouples from ordinary matter as the universe expands and cools
  - Still around today with densities of about a few per liter



- Supersymmetry produces a theoretical candidate (LSP), but others exist (e.g. Kaluza-Klein particles, ...)

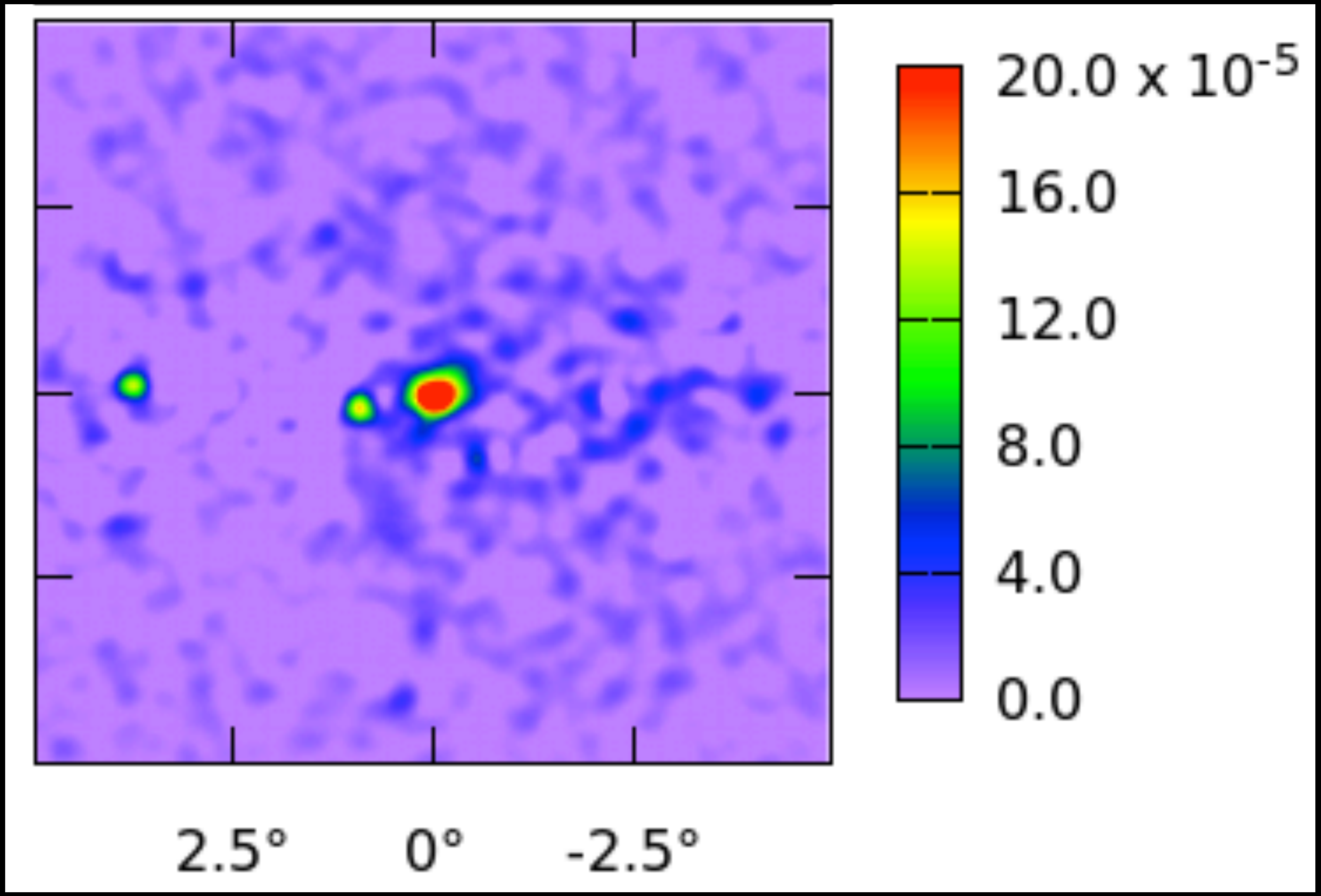
WIMPs not necessarily related to supersymmetry

- Dark sector could be as complicated as standard model
- Searches not limited by expectations from SUSY models



How do we find it?

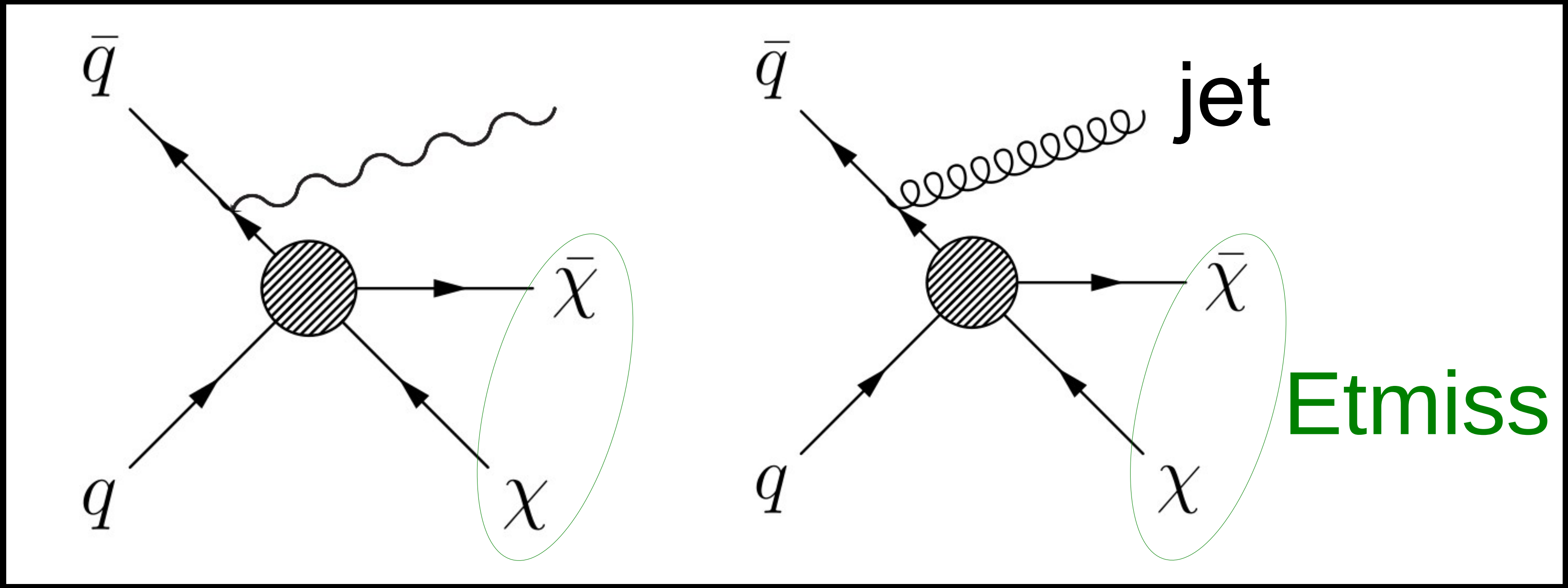
- Indirect - detect annihilation products from regions of high density like the sun or the center of the galaxy



Fermi-LAT gamma ray excess at center of galaxy
Daylan, Hooper et al., 1402.6703

How do we find it?

- Indirect - detect annihilation products from regions of high density like the sun or the center of the galaxy
- Accelerators - create a WIMP at the LHC
  - Missing ET and mono-X searches



How do we find it?

- Indirect - detect annihilation products from regions of high density like the sun or the center of the galaxy
- Accelerators - create a WIMP at the LHC
  - Missing ET and mono-X searches
- Direct detection - WIMPs can scatter elastically with nuclei and the recoil can be detected